Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

July 1961

Atomization of Liquid Fuel

Detecting Power Plant Service Failures

Putting the Digital Computer to Work

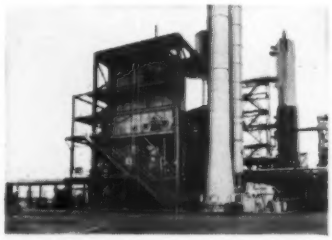
Repeated Acid Cleaning of Boilers

How C-E helps make clean air from an important refinery by-product

Many refineries use catalysts to "crack" crude oil into numerous petroleum products. But the catalysts eventually become poisoned and must be regenerated before they can be re-used. The regeneration process produces large quantities of hot, carbon-monoxide-bearing gas. Until recently, this gas—theoretically combustible—was discharged to the atmosphere because there existed no practical way to burn it.

Combustion Engineering, recognizing the concern with which refineries viewed this problem, directed the attention of its fuel experts and boiler designers to it. The result—C-E's CO Boiler. This efficient unit completely burns catalyst regenerator gas and discharges to the atmosphere carbon dioxide and water vapor, both normal atmospheric components. In addition, it generates large quantities of steam to help meet the refinery's process steam or power needs.

A formerly unusable marginal fuel is now doing productive work, and a contaminant has been removed from the air we all breathe. This advance in the disposal of industrial by-product waste is an example of how Combustion Engineering serves not only industrial America but the general public as well.



The C-E boiler pictured burns catalyst regenerator gas. This lean, hot, marginal fuel contains carbon monoxide which, when completely burned, generates sizeable quantities of steam for refinery use. The carbon monoxide is consumed in the boiler, preventing its discharge to atmosphere.

C-313

COMBUSTION ENGINEERING

C-E

GENERAL OFFICES: Windsor, Conn.
NEW YORK OFFICES: 200 Madison Avenue, New York 16

All types of Steam Generating, Fuel Burning and related equipment; Nuclear Reactors; Paper Mill equipment; Pulverizers; Flash Drying Systems; Pressure Vessels; Soil Pipe

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03

Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

volume 33 number 1 **July 1961**

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BPA

COVER PHOTO

Striking night view of the Roy S. Nelson Station, Gulf States Utilities Co.

(Photo courtesy of Allis-Chalmers Electrical Review)

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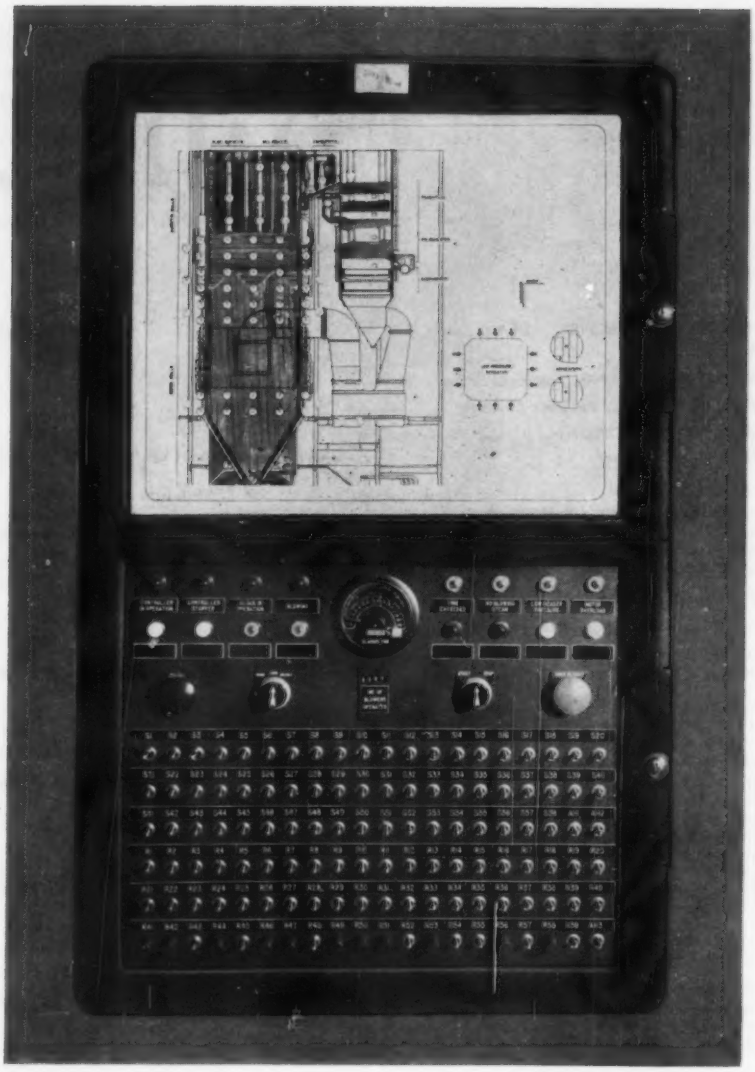


Selective-Sequence Controller

Up to 120 electrically-driven long retractable Vulcan soot blowers can be controlled by this SSC-120 controller. With it the operator can monitor the complete blowing program and get an instant report should there be any malfunction. In such case, interlocks automatically stop the blowing until a correction is made.

Vulcan Selective-Sequence control offers the greatest flexibility in automatic soot blowing. It permits varying the sequence by individual blowers — at any time, and in any way found desirable to improve boiler cleaning or to save blowing medium. Tied to a built-in clock, it permits 24-hour scheduling with three or more sequences.

Vulcan Automatic-Sequential Control permits the operator to pre-select any number of units to be operated individually — not necessarily by zones or bands. Without leaving the panel he can revise the sequence at any time, or switch instantly to single-unit operation.

Both control systems are described in Bulletin 1029. Write for it.

With either system: A new console-mounted miniature panel provides even greater convenience and efficiency. Soot blowing may be tied to some such phase of boiler operation as steam temperature control, a refinement with which Vulcan has had more than six years of experience. And for the ultimate in soot blower control, the Vulcan system can be tied in with computer operation of the plant.

Vulcan "Automated" Soot Blowing

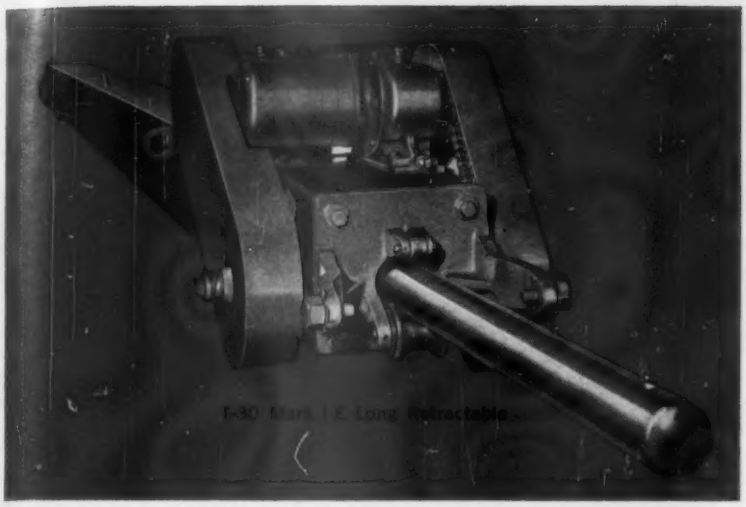
Modern boilers must be kept clean to operate efficiently—but the cleaning itself must be done efficiently to match modern operating procedures.

Vulcan precisely-controlled automatic soot blowing systems meet this specification.

They save time. One blower automatically follows another as programmed. Indexing is a matter of seconds.

They save labor. Merely pushing a button starts automatic operation. The operator or computer controls the whole system from one central location.

They save fuel. Cleaning is better because operation is positive and at proper intervals. Steam—which means fuel—and air are saved because of precise timing.



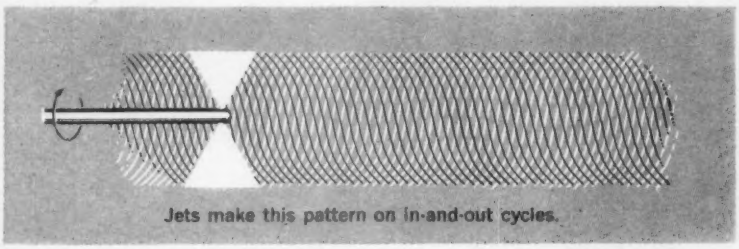
Vulcan RW-3E Wall Deslagger

The high striking power of this electrically-operated deslagger drives off gummy, clinging masses or sintered ash to minimize average slag thickness. One motor extends and retracts the lance almost instantly. The other motor rotates the lance slowly for optimum cleaning. Air, saturated or superheated steam, or water—or any combination—can be used as the blowing medium. Blowing pressure may be adjusted while blowing. Maintenance is easy. Write for Bulletin 1034. Model RW-3A is air-driven. Write for Bulletin 1066.

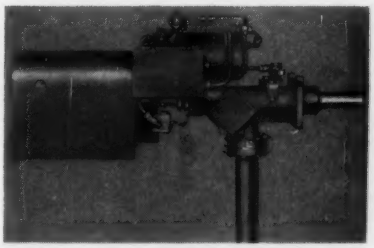
Long Retractable Soot Blowers

The electrically-driven T-30 Mark I-E is the most modern long retractable soot blower for travels up to 24 feet. It has dual-motor drive. One motor moves the lance in and out. This can be a 2-speed motor to save blowing medium. The other rotates the lance—always in the same direction. The special-alloy lance can be used in almost any temperature. Low rotating speed increases range and penetration of cleaning, decreases wear, and eliminates whip. Write for Bulletin 1063. The T-30 Mark I-A, Bulletin 1073, is air-driven. For travels greater than 24 feet, the Vulcan T-30, Bulletin 1030, is used.

Rotary Soot Blowers with electric, air or manual operation are available for use in lower-temperature zones. Write for Bulletin 1072.



Jets make this pattern on in-and-out cycles.



Multi-Helix Jet Path

Because Vulcan long retractables have dual-motor drive, lance rotation is continuous with no stop-step action at the end of travel. The two jets always follow a different path in and out, forming an infinite number of reversed-helix paths on repeated cycles. This means thorough cleaning of all heating surfaces, minimized danger of tube erosion, and prolonged packing life.

saves time, saves labor, saves fuel

And maintenance is low. Each component of a Vulcan system is designed with maintenance men in mind.

Write for the bulletins mentioned on these pages. Copes-Vulcan Division, Erie 4, Pennsylvania.

Copes-Vulcan Division

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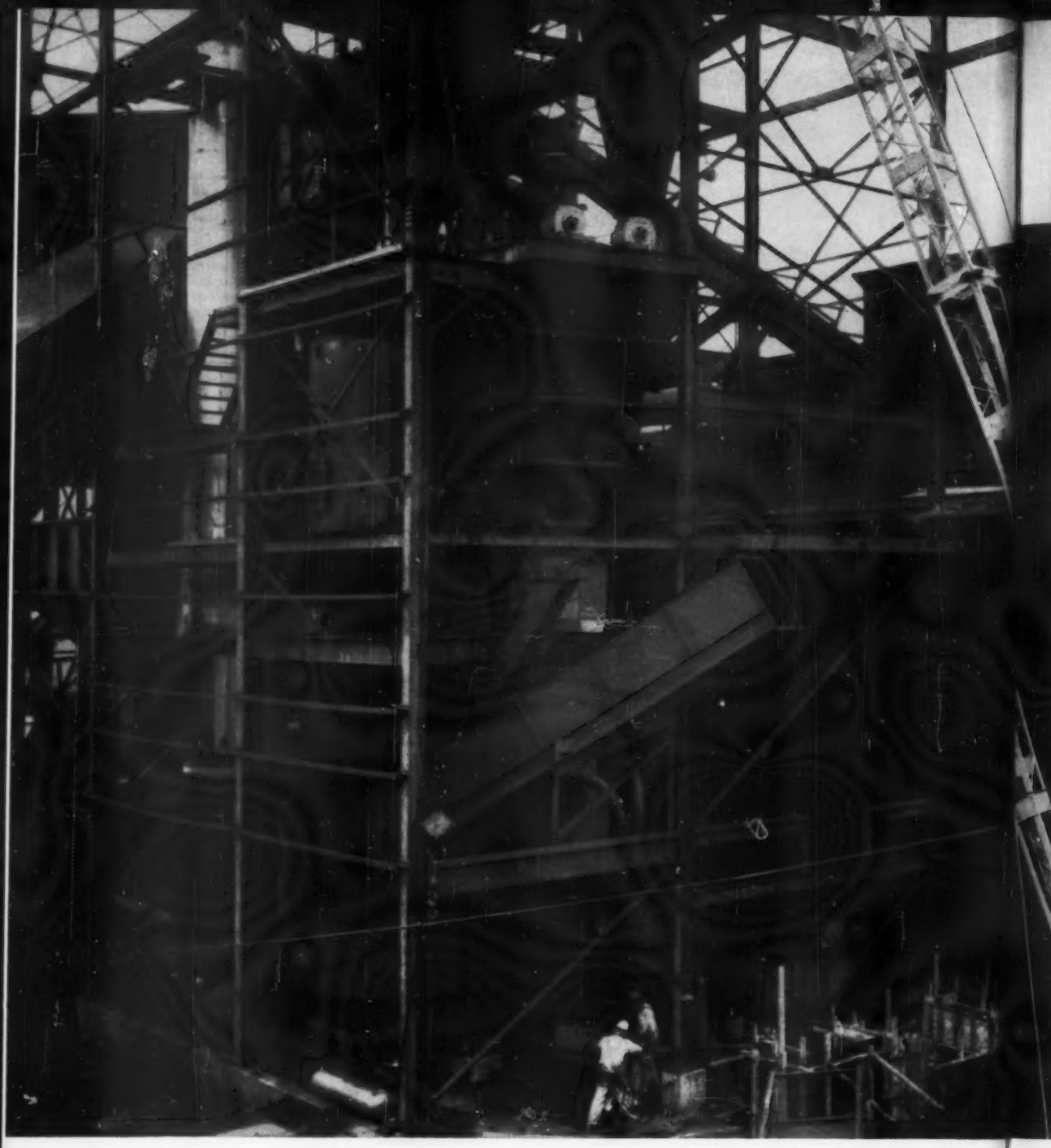

Progress Report: *Eastern's new cleaning plant at* ***Federal No. 1 mine, Grant Town***

ON SCHEDULE

The construction of the new coal cleaning plant at Eastern's Federal No. 1 mine, Grant Town, W.Va., is proceeding on schedule.

Designed by Eastern's own engineering staff, the new plant will employ the most modern equipment, so arranged as to provide uninterrupted production at all times. This plant will produce a very high grade of steam coal.

(Left) Main plant showing the dryer at left, pulverizer (at base of dryer) and part of the dust collector system.

(Below) Company and contractor personnel check progress of 2500 ton capacity blending bin adjacent to main plant.

Federal No. 1 is one of a series of such cleaning plants now under construction or in the planning stage. These plants are evidence of Eastern's determination to continually improve their product and their service to customers.

If you would like a full description of the facilities at Federal No. 1, write or phone your nearest Eastern representative.

EASTERN GAS AND FUEL ASSOCIATES

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BEACON COAL

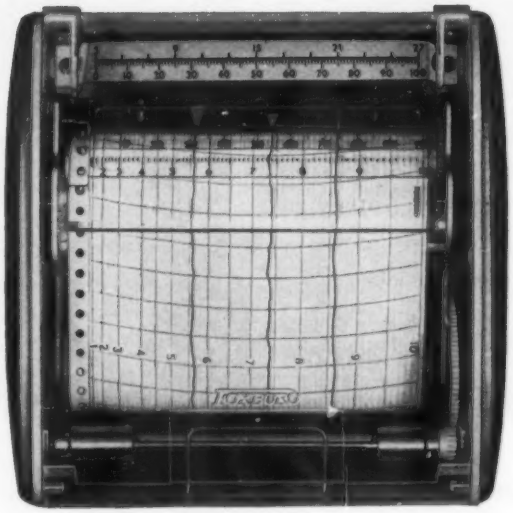
Foxboro CONSOTROL* Recorders

Yes, you can actually mount up to 4 Foxboro Consotrol Recorders in the panel space ordinarily required for one conventional-size instrument — and get a full-scale, 4"-wide chart record from each one! Or, using 3-pen Consotrol Recorders, get a total of 12 full-size records in the same panel space!

This unique combination of compactness and high readability is in *addition* to the outstanding convenience Consotrol Recorders provide. They're by far the simplest to maintain . . . inking only once every 6 months; chart replacement every 30 days. And the chart loads quicker and easier than a box camera!

With Consotrol Recorders you can put records of *all* important trends on your console without crowding or limiting visibility. The same compact Consotrol design also is available with automatic control functions. Get full details on the complete modern Consotrol Line. Write for Bulletin 13-18. The Foxboro Company, 277 Norfolk St., Foxboro, Mass.

*Reg. U. S. Pat. Off.



(½ actual size)
Available in 3-27 psi or
3-15 psi air signal

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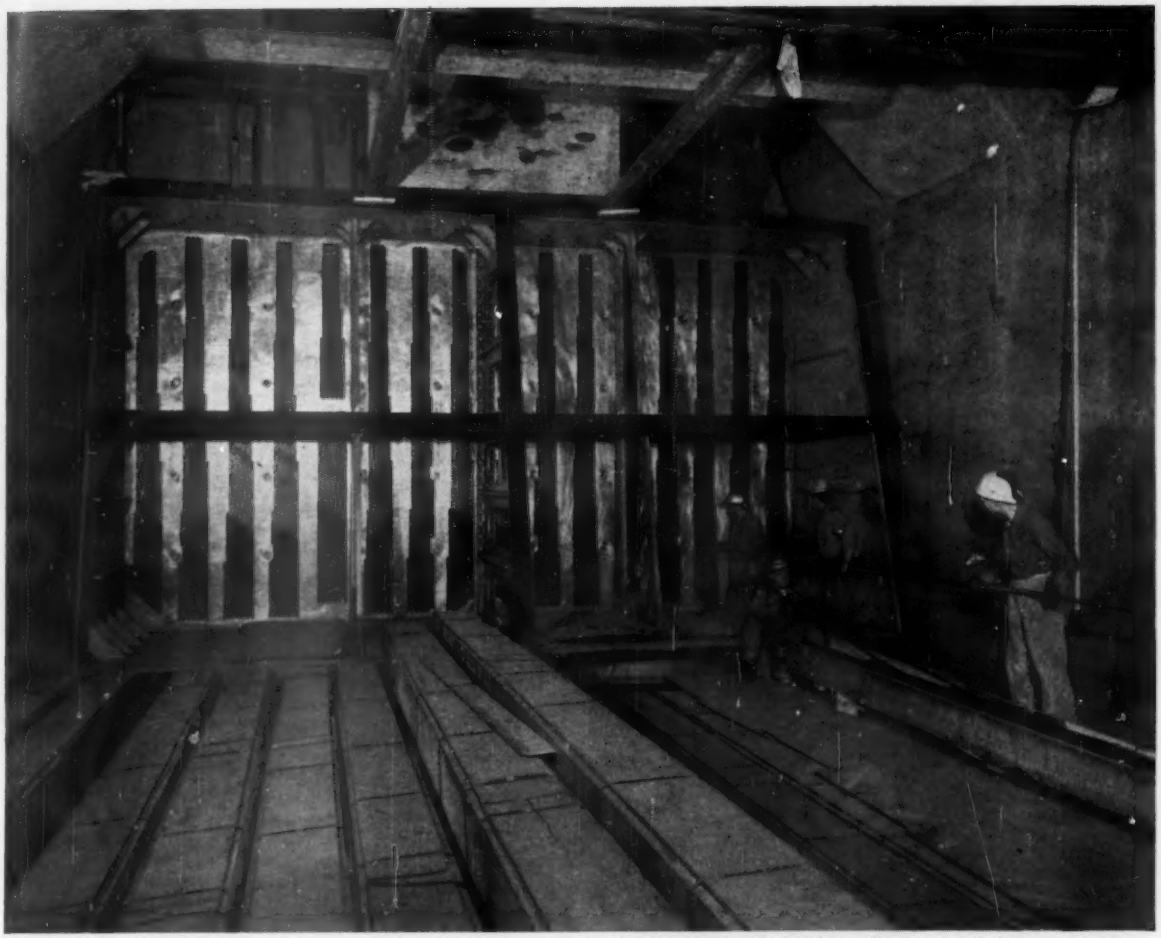
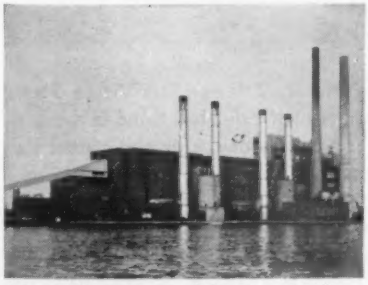


ARSENICAL ADMIRALTY TUBES being installed in the condenser of St. Clair Unit No. 6. The condenser has four Leaded Muntz Metal tube sheets, each 143½" x 161" x 1½", weighing altogether 42,443 pounds, also furnished by Anaconda American Brass.

Arsenical Admiralty Tube totaling 367,000 lb. installed in condenser of Detroit Edison's new St. Clair Unit No. 6

The new 325,000-kw St. Clair Unit No. 6 of the Detroit Edison Company has a condenser with a total cooling surface of approximately 170,000 square feet—one of the largest ever built.



The **ST. CLAIR PLANT** of the Detroit Edison Company.

Anaconda supplied 21,900 tubes of Arsenical Admiralty-439, each ¾" O.D. x .049" (18 BWG) wall x 40' long, for a total weight of about 367,000 pounds. Anaconda also furnished the huge Leaded Muntz Metal tube sheets required.

Constantly studying corrosion problems affecting condensers and heat exchangers, Anaconda American Brass is a leader in the development of alloys to meet the needs of the industry. Arsenical Admiralty is one of its contributions. The latest, a new high-strength copper-nickel-iron tube alloy for feedwater heaters, Cupro Nickel, 30%-707, was just recently announced.

TECHNICAL ASSISTANCE. Anaconda has also enlarged its team of metallurgical engineers specializing in the condenser and heat exchanger field. The services of these men in water analysis, the solution of corrosion problems, and the selection of alloys are available to you through your Anaconda American Brass representative. Or write: Anaconda American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.

6150

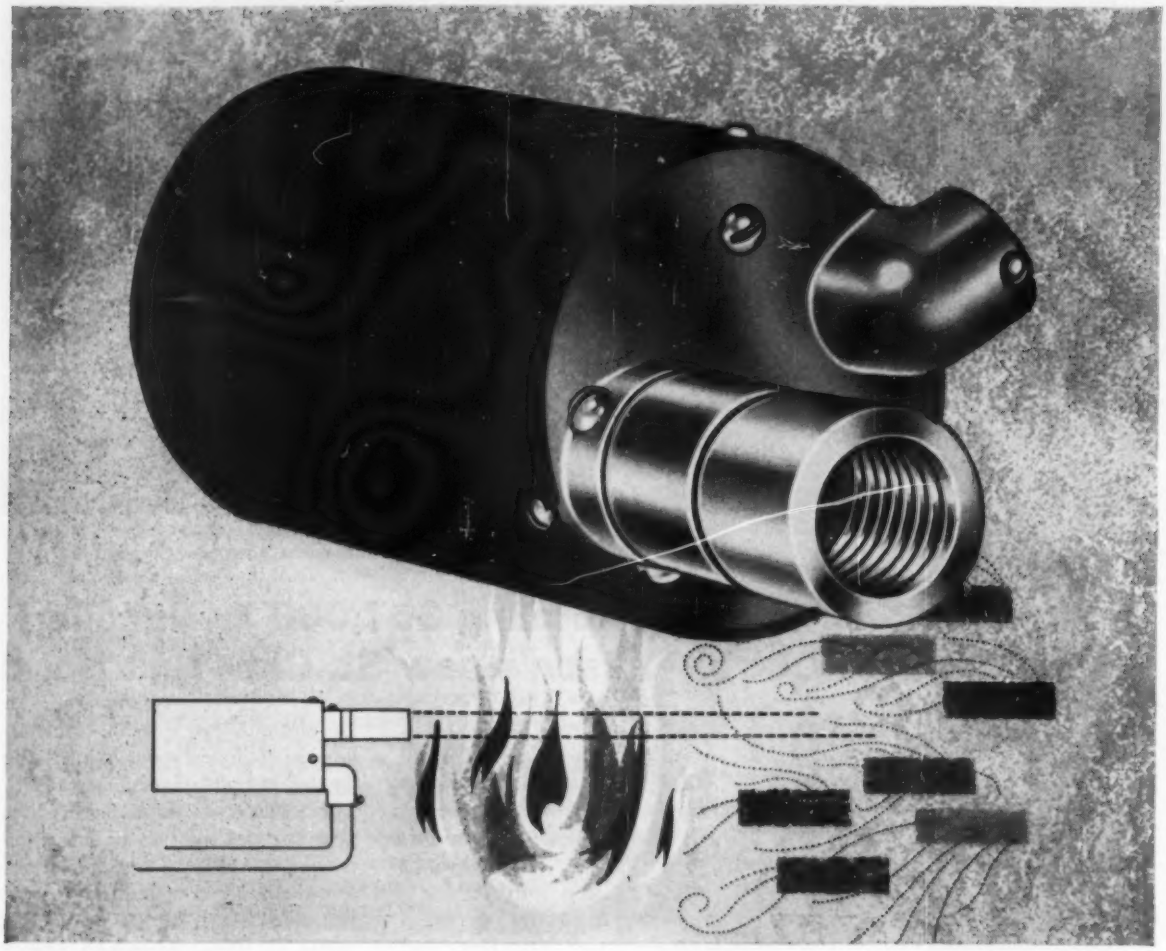
ANACONDA®

Tubes and Plates for Condensers and Heat Exchangers

Anaconda American Brass Company

Undetected flame failure can cause costly interruptions, do serious damage to expensive equipment and endanger lives. To prevent such loss, Honeywell has developed an ultraviolet flame detector that won't be fooled, because it positively differentiates between flame and hot brick.

This flame detector



Now, for the first time, you can be absolutely sure that fuel delivery will be stopped in the absence of flame. Honeywell's new C7012A Ultra-Vision* Flame Detector employs an amplified ultraviolet signal to positively distinguish between an actual flame (ultraviolet rays) and a hot refractory (infrared rays). This revolutionary new ultraviolet sensor represents a major breakthrough in scientific flame detection.

Because this compact new control device is not sensitive to a hot refractory, flame supervision of both single and multiple burners is simplified. The Ultra-Vision Flame Detector can be aimed at each individual flame in the most convenient way. It is the only device on the market that offers you this advantage.

Best of all, this new flame detector saves you money. Wiring is less expensive in this system than in a lead sulphide cell. It is easier to install because hot refractory can be ignored. And there is no further need for flame rod replacement.

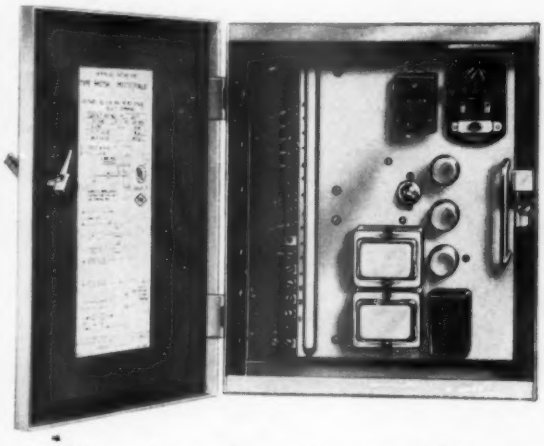
senses only the flame!

New Honeywell Protectoglo relay assures "maximum safety"

Available for use with the Ultra-Vision Flame Detector or with standard flame rods is Honeywell's famous R4075 Protectogl relay.

This new relay features "maximum-safety" self-checking which is particularly desirable for continuously burning industrial burners. A self-checking circuit checks the circuit and the components of the Protectoglo *once every second.*

The mounting cabinet of the Protectoglo has all-voltage terminals and a quick-disconnect control base that enables you to remove the relay without disconnecting any of the wiring. Plug-in components can easily be removed and replaced if necessary.



In addition, flame-rod assemblies are available to meet every industrial application. Alarm contacts can be powered from separate line or low-voltage circuit. And a special zinc dichromate finish resists the corrosive effects of most industrial atmospheres.

*Trademark

Honeywell protects Los Angeles' new $65,000,000 power plant

Los Angeles' Department of Power and Water installed the Honeywell Ultra-Vision Flame Detector and Protectoglo System to insure maximum flame safeguard protection for its new Scattergood Steam Plant. This huge power facility covers a 57-acre ocean front site south of the Playa del Rey district of Los Angeles.

The plant now uses two 91-foot-long turbine generators to produce 320,000 kilowatts of power. When the entire complement of six generators is put into operation, the anticipated output will be 1,200,000 kilowatts.

Gas, oil or a combination of both fire the Scattergood boilers. Gas consumption under full load is approximately 1,520,000 cubic feet per hour, and oil is used at 250 barrels an hour. Boilers are 133 feet high and furnace volume is 65,000 cubic feet.

For full information about Honeywell Flame Safeguard Control Systems, call your nearby Honeywell office. Or write Honeywell, Dept. CN-7-23, Minneapolis 8, Minnesota. In Canada, write Honeywell Controls, Limited, Toronto 17, Ontario.

Honeywell

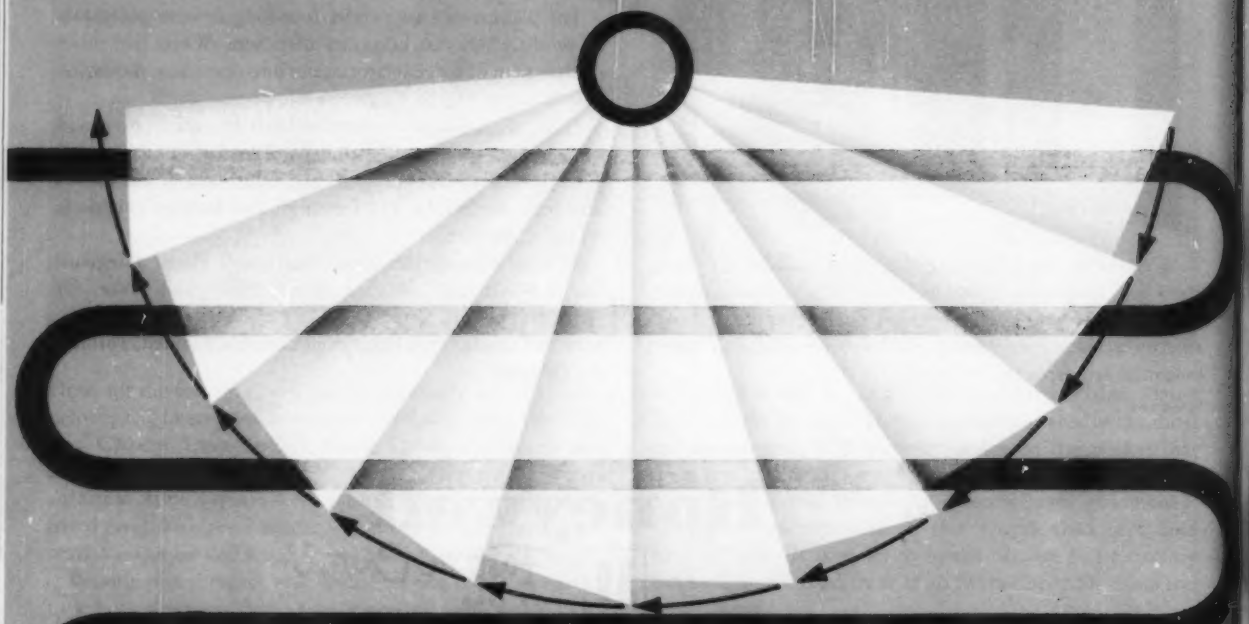
H HONEYWELL *First in Control*

SINCE 1885

Diamond developed for more economical power.

AIR PUFF BLOWING=CLEANER BOILERS..
AN APPRECIATIVE PUBLI

THIS.....



Shaded area indicates sustained effective cleaning pattern.

Two of today's more critical conditions for efficient steam generation . . . clean boilers and acceptable stack emission . . . are assured with Diamond Air-Puff Soot Blowing Systems.

Increased cleaning efficiency is obtained because high density air is used as the cleaning medium and emitted in sustained high pressure puffs that are independent of receiver capacity or compressor size. Also, because no air is emitted at ineffective low pressures, there's greater economy in *use* of cleaning medium.

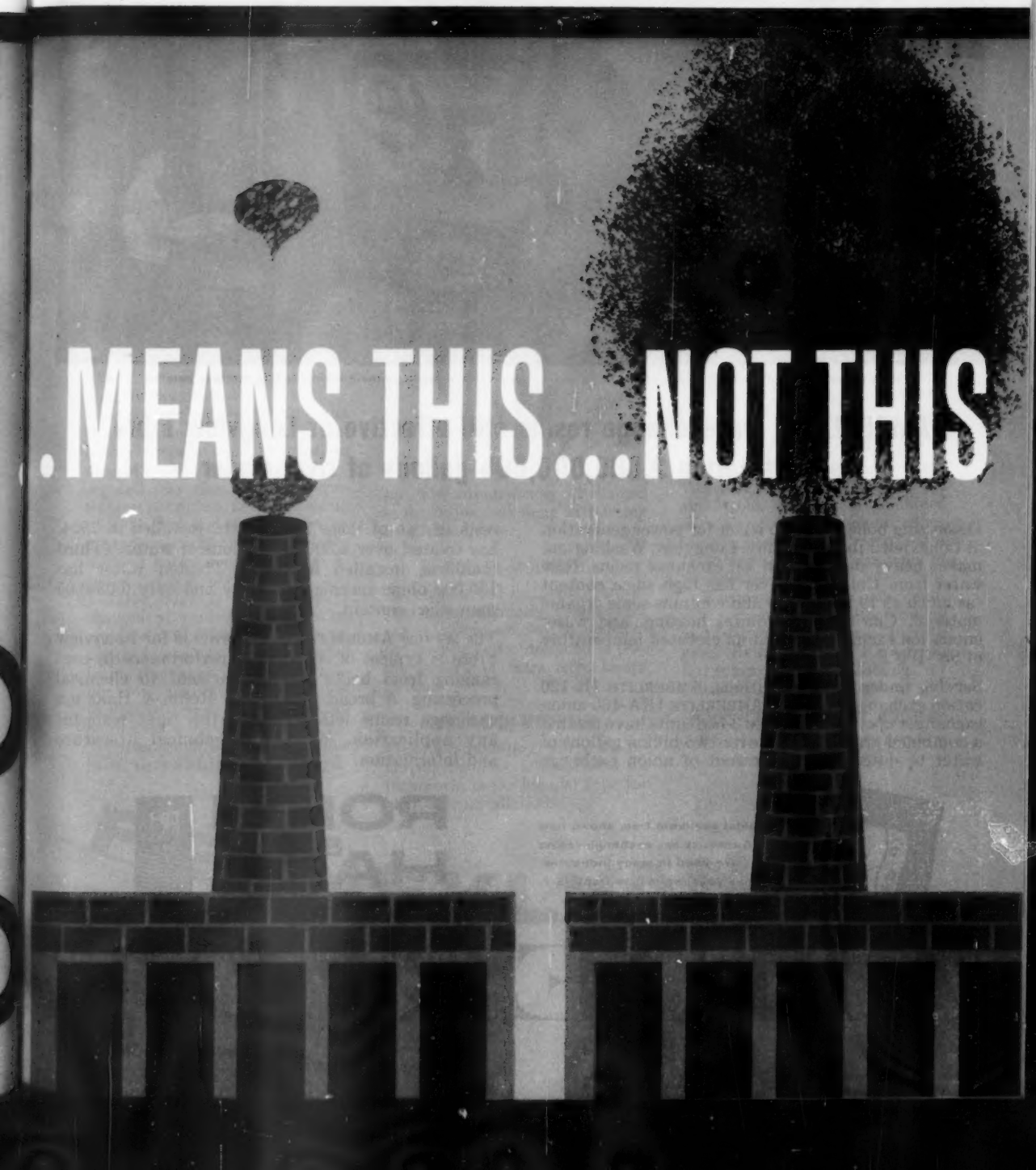
Acceptable stack emission is achieved because intermittent air puff blowing eliminates more concentrated and objectionable emission caused by continuous blowing arcs or blowing puffs of longer duration. In the standard Diamond Air-Puff System, intervals between air puffs are determined by the time required for build-up to optimum blowing pressure; however, if more positive control of stack emission is desired, intervals can be regulated by a simple valve adjustment.

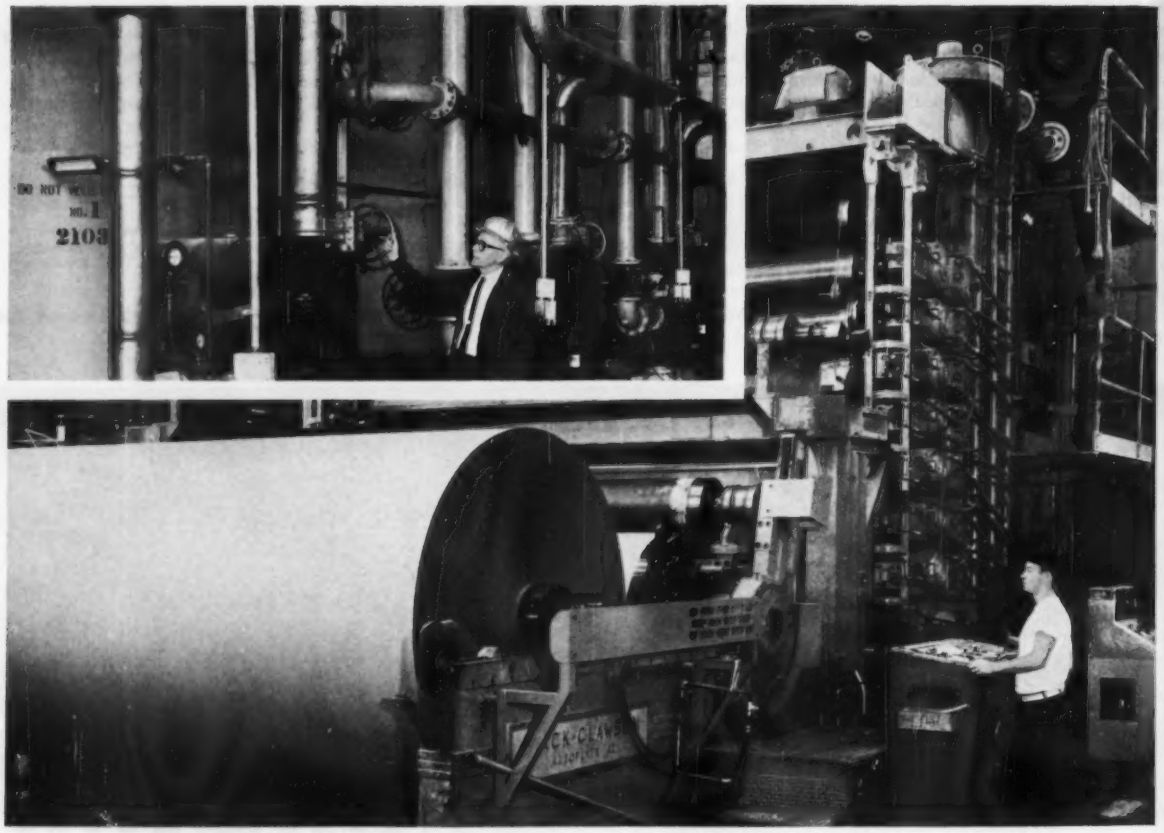
The Diamond Air-Puff Blowing System for new *or* existing boilers of any type and capacity is further evidence of why "Diamond developed" means more economical power. Our engineers will be happy to discuss its application to your units. Call, write or wire for complete information . . . and thank you for reading our advertisement.

POWER

This is the new trademark of Diamond Power . . . a symbol of quality, integrity and progress . . . in products, systems and service.

DIAMOND POWER SPECIALTY CORPORATION, Lancaster, Ohio
DIAMOND SPECIALTY LIMITED, Windsor, Ontario





INSET: Ion exchange units at Longview Fibre Company, Longview, Washington. Three 2-bed systems operate in parallel.

AMBERLITE® ion exchange resins still effective at Longview Fibre after treating 2,000,000,000 gallons of river water

Deionizing boiler makeup water for power generation at Longview Fibre Company, Longview, Washington, makes heavy demands on ion exchange resins. Raw water from Columbia River has high silica content (as much as 19 ppm SiO_2) and contains some organic material. Clarification requires heating, and water enters ion exchange beds at an elevated temperature of 95°-100°F.

Serving under these conditions, AMBERLITE IR-120 cation exchange resin and AMBERLITE IRA-400 anion exchanger operating in three 2-bed units have treated a combined grand total of over two billion gallons of water to date. Each cubic foot of anion exchange resin in two of these 2-bed units, installed in 1954, has treated over 4,300,000 gallons of water. (Third unit was installed in 1957.) Treated water has 750,000 ohms specific resistivity and only 0.03-0.05 ppm silica content.

The service AMBERLITE resins provide for Longview Fibre is typical of AMBERLITE performance in uses ranging from boiler water treatment to chemical processing. A broad selection of Rohm & Haas ion exchange resins lets you pick the right resin for any application. Write for technical literature and information.

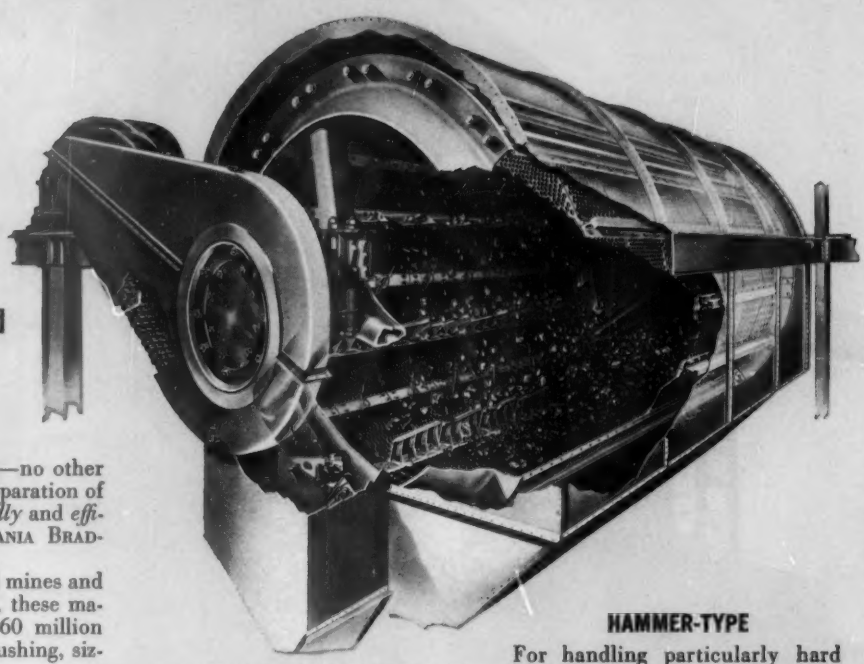
Booklet available free, shows how AMBERLITE ion exchange resins are used in many industries. Address your request to Dept. IE-7.

ROHM & HAAS

PHILADELPHIA 5, PA.

AMBERLITE

For maximum economy in preparation of ROM coal—it's PENNSYLVANIA BRADFORD BREAKERS



Trunnion-mounted
Roller-mounted
Hammer-type

Mine-side or plant-side—no other crusher handles the preparation of ROM coal as *economically* and *efficiently* as a PENNSYLVANIA BRADFORD BREAKER.

At power plants, coal mines and by-product coke plants, these machines prepare over 160 million tons of coal a year—crushing, sizing and scavaging all in one continuous operation, at capacities up to 1500 TPH, and at average maintenance costs as low as $.001 per ton and power consumption averaging .204 KW per ton.

ROM coal is continuously charged at loading end. Passing sizes are immediately screened out. Larger lumps are raised by radial lifting shelves and dropped, breaking along natural cleavage planes to desired screen size, with minimum fines.

Refuse such as bony, sulphur balls, slate and rock, resist breakage, are automatically discharged at the refuse end along with tramp iron, timbers, etc.

ROLLER-MOUNTED

Roller-mounted BRADFORD BREAKERS are particularly adapted for use at coal mines, as the spider at the loading end is designed to permit loading of extra large lumps of coal.

TRUNNION-MOUNTED

Trunnion-mounting, where the revolving cylinder is suspended on trunnions, is the popular type for plant-side installations.

HAMMER-TYPE

For handling particularly hard coals, or for heavier loading, the BRADFORD BREAKER is combined with a concentrically-mounted rotor of a hard-hitting PENNSYLVANIA HAMMERMILL at the rear end of the breaker.

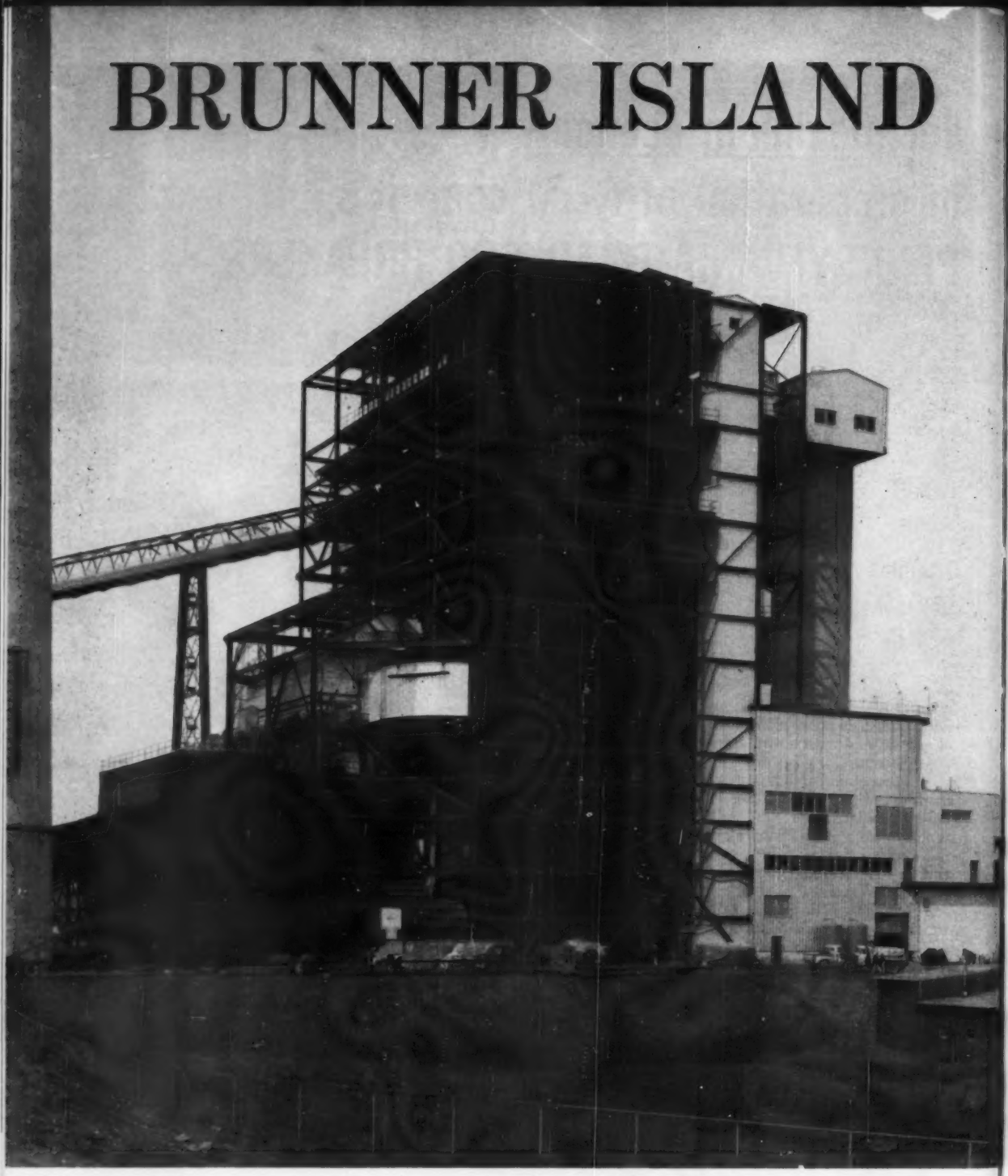
Whatever the type most suitable for your need, if it's *economy* and *efficiency* you want—investigate PENNSYLVANIA BRADFORD BREAKERS. Write for catalogs, or call a Pennsylvania Engineer.

PENNSYLVANIA CRUSHER DIVISION
BATH IRON WORKS CORPORATION
WEST CHESTER, PENNA.

PENNSYLVANIA CRUSHERS

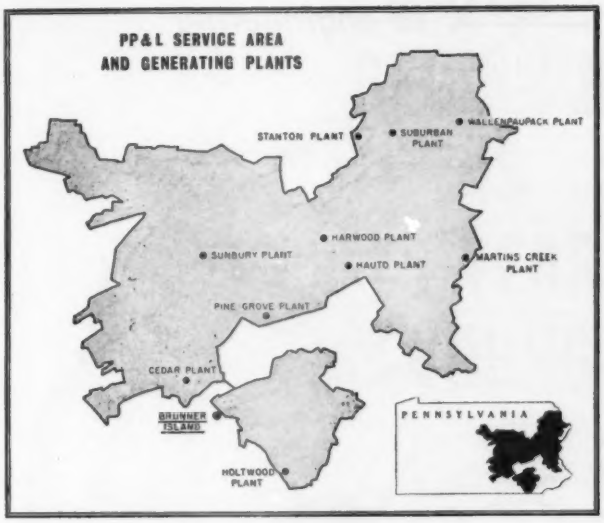
BATH-BUILT

BRUNNER ISLAND



Specifications:

Unit	C-E Controlled Circulation radiant reheat type with divided furnace
Primary Steam Flow	2,100,000 lb/hr
Design Pressure	2,750 psi
Operating Pressure	2,500 psi
Superheat/reheat Temperatures	1005F/1005F
Fuel	Pulverized coal
Fuel Burning Equipment	Tilting Tangential burners supplied by 5 C-E Raymond Bowl Mills



New 300,000 kw station goes into service

When Unit No. 1 at the new Brunner Island Steam Plant was placed in commercial operation on June 22nd, Pennsylvania Power & Light Company expanded its system's capability to over 1.8 million kilowatts.

Steam for the 300,000 kw cross-compound, quadruple-flow turbine is supplied by a C-E *Controlled Circulation* steam generator designed for outdoor service. Photograph of the new outdoor station during final stage of erection, and brief specifications, appear on the opposite page.

The Brunner Island unit—largest in PP&L's system—is located on the Susquehanna River at York Haven, Pennsylvania, about fifteen miles downstream from Harrisburg. Ebasco Services, Inc. were the consulting engineers.

COMBUSTION ENGINEERING

C-325

General Offices: Windsor, Conn.
New York Offices: 200 Madison Avenue, New York 16, N. Y.

NEW UTILITY STATIONS C-E EQUIPPED

Includes only new stations on new sites placed in operation since JANUARY 1, 1950

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Hutchison
Yates
Dunkirk
Titus
Lee
Contra Costa
Hawthorn
Ninemile Point
Edge Moor
Palatka
Johnsonville
Danskammer
Beckjord
Highgrove
Plant X
Black Dog
Albany
Joppa
Meramec
Portsmouth
Lake Creek
Etiwanda
Aurora
Hennepin
Eastlake
Oak Creek
Suwannee River
Urquhart
Kingston
Sandow
Mullergren
Barry
North Omaha
Wilmington
Carbon
Saguaro
Morro Bay
Vermilion
John Sevier
Collin
Milliken
Canaday
Gallatin
Barrett
Mitchell
San Bernardino
Yorktown
Gulf Coast
Tucson
Port Wentworth
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Allen
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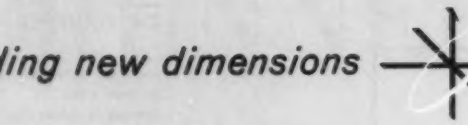
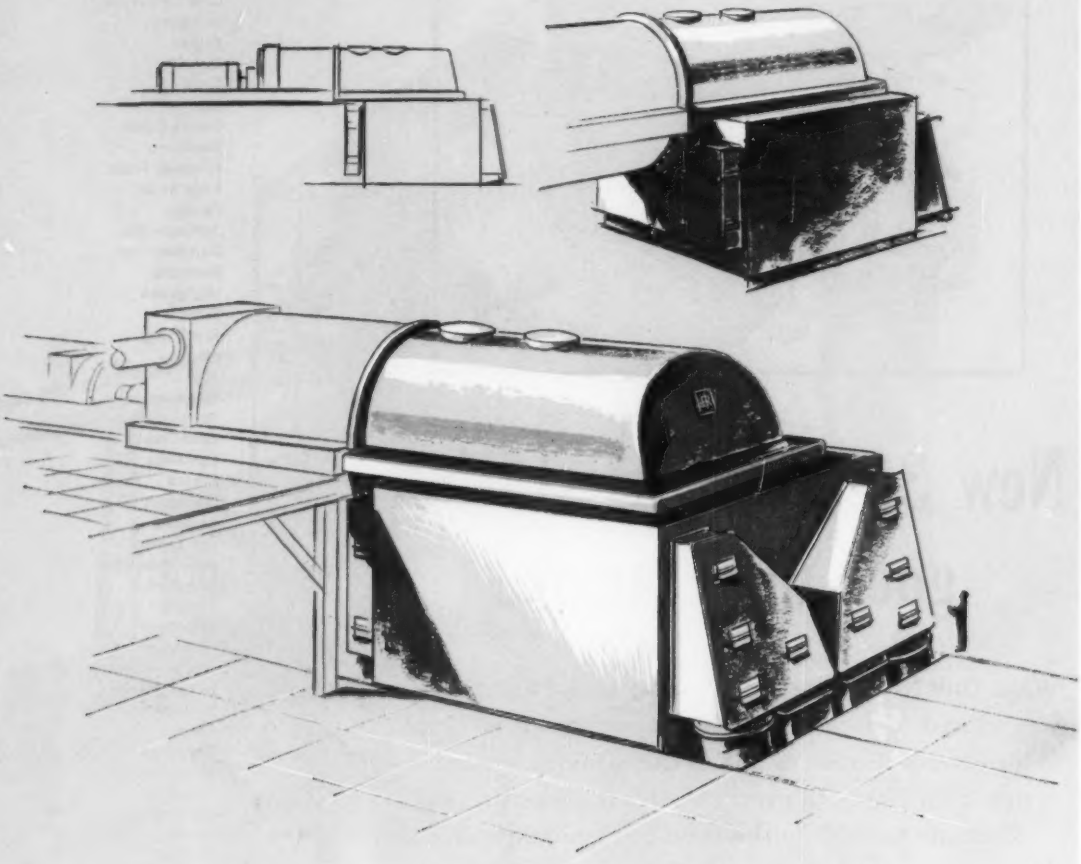
Adding new dimensions  *to engineering*



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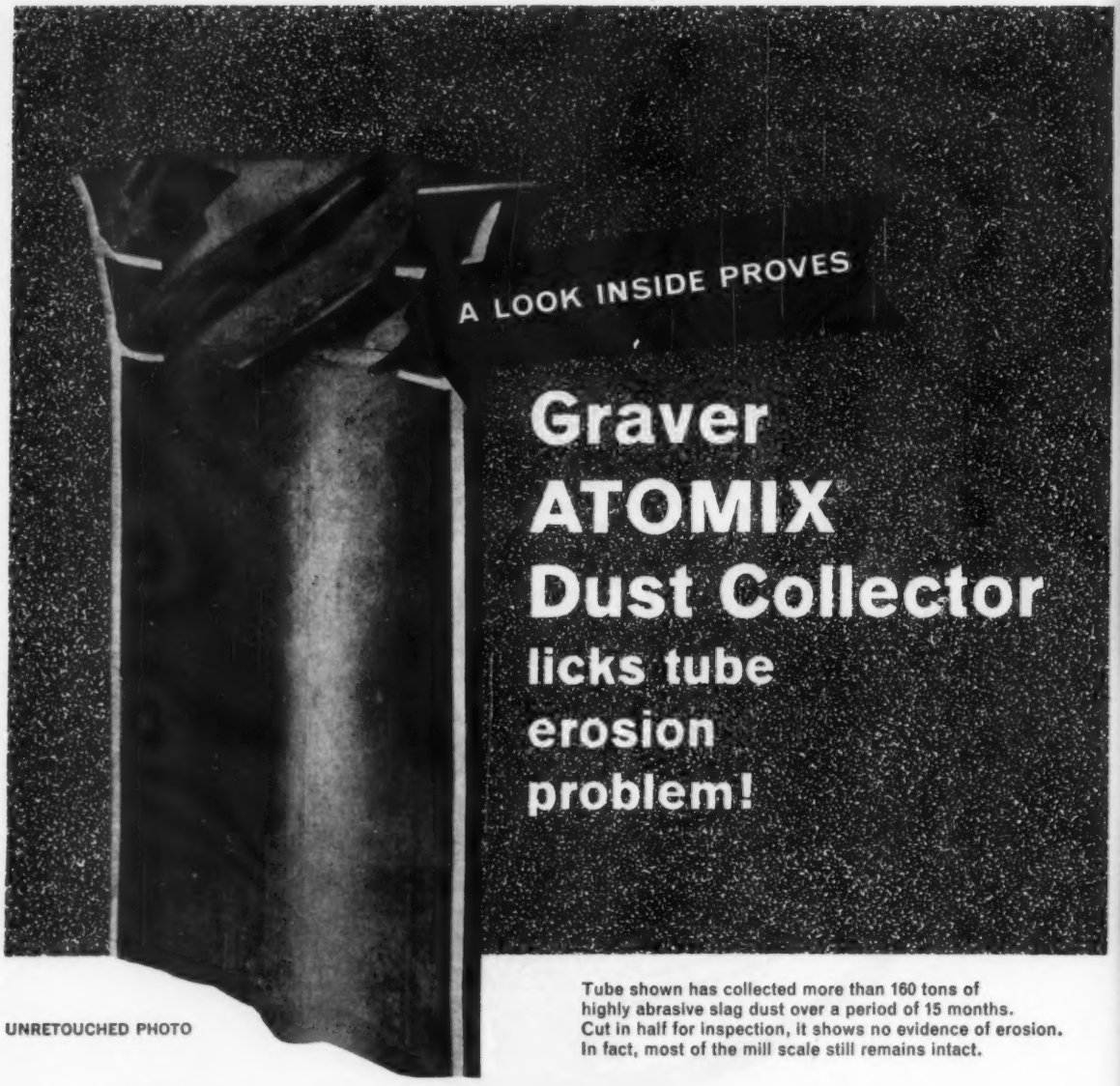

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Tube shown has collected more than 160 tons of highly abrasive slag dust over a period of 15 months. Cut in half for inspection, it shows no evidence of erosion. In fact, most of the mill scale still remains intact.

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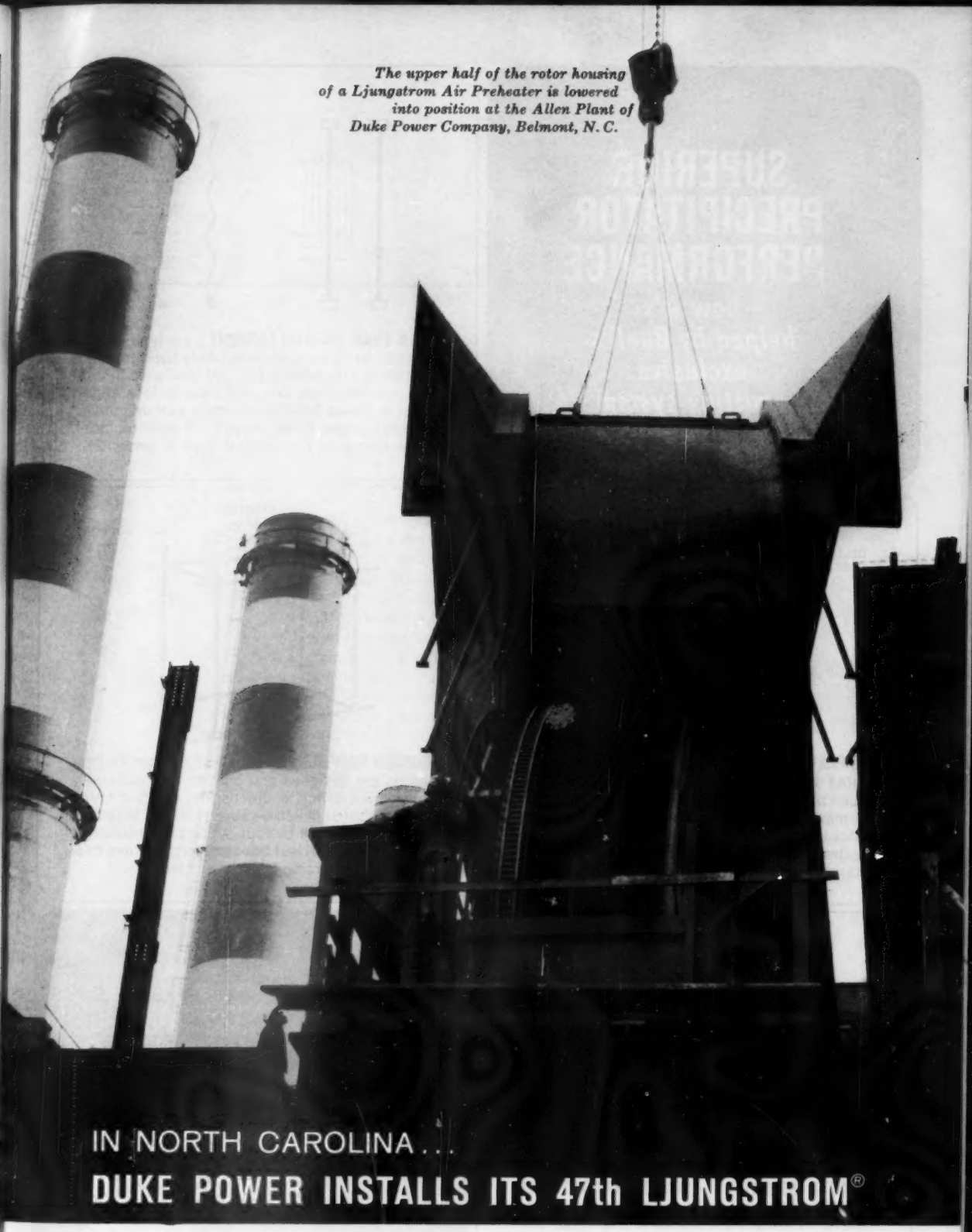

The upper half of the rotor housing of a Ljungstrom Air Preheater is lowered into position at the Allen Plant of Duke Power Company, Belmont, N. C.

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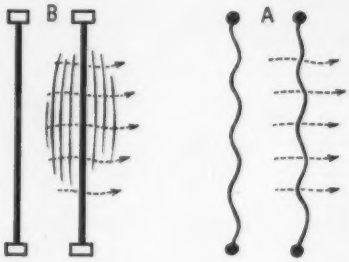
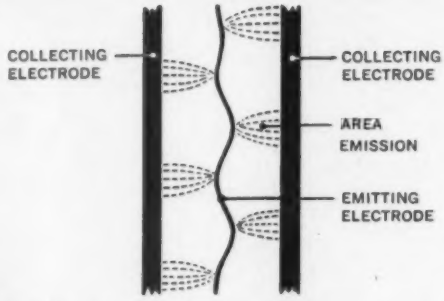
—how it's helped by Buell's exclusive emitting system



LESS THAN 2% REPLACEMENT — Each stainless steel Buell Spiralectrode is firmly fixed top and bottom to a rigid frame (A). Self-tensioned in this way, the electrode does not sway or lose alignment as shown at (B), even under current surges or varying gas flows. Buell's 10-year replacement record in this critical area is under 2%.



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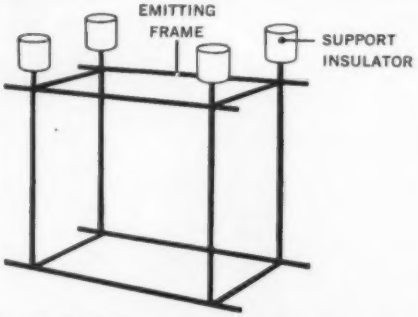

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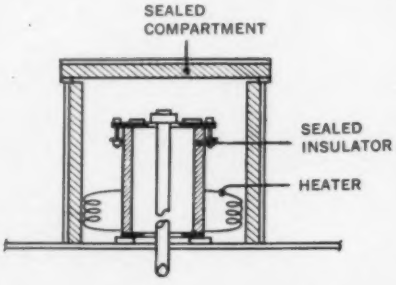

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Combustion

EDITORIAL

On Intuition

Our favorite British colleague, Capricorn, has caught our fancy again. This week he intrigued us by deploring the paucity of feminine engineers in Britain—an intolerable condition for a profession which stands in such great need of intuition, says our English friend.

We are well aware that members of the gentler sex are endowed with many gifts and of these we believe the most universal is intuition. But what need has an engineer for intuition? Look a moment at this situation.

Five engineers are given the same basic data for solving the same problem. They approach solution along the same trail but they will invariably use different stepping stones—a faulty estimate here, a biased premise there, here a conservative prediction, there an ultraconservative assumption until, if the train is long enough, they must present four or five different solutions. These may range all the way from "It would be criminal to build now" to "you'll be out of business in five years if you fail to build now, and build big."

How then is a proper engineering decision to be made? The general methods of engineering have been religiously followed but how divergent are the results! Oliver Wendell Holmes explains "General propositions do not decide concrete cases. The decision will depend on a judgment or *intuition* more subtle than any major premise." (*Italics ours*).

The vagaries of personality that constitute the nature of each of us—not inaccuracies of engineering science—are what lead us astray. But what is to be done? What kind of man is needed to render the decision? Wordsworth has an answer for us:

> "One in whom persuasion and belief
> Had ripened into faith, and faith become
> A passionate intuition"

The engineer with true greatness has a very real intuition based on faith in himself, in his society and in a Divinity that ordains these things. His intuition or faith will guide his decision. And having made a decision his faith will move him to implement it—to make it the right choice.

So we extend to Capricorn our thanks for a stimulating idea and to you we extend our regret that we're unable to tell you how to determine which men on your staff are possessed of the essential, (and by no means exclusively feminine) gift of intuition.

Atomization in a liquid fuel combustion system is considered as a mass transfer operation, and the factors influencing the rate of evaporation of drops and sprays are discussed. The mechanisms of liquid disintegration are detailed and the practical means of achieving clouds of finely divided drops from atomizers are described.

Atomization of Liquid Fuel for Combustion—I*

By PAUL EISENKLAM†

Imperial College of Science and Technology

IN RECENT years, the science of combustion has advanced at a most stimulating pace and much analytical information is becoming available which puts many aspects of the design of liquid fuel combustion chambers on a firmer scientific basis. The role of atomization, however, has not yet been fully incorporated within the frame of the factors which influence such combustion systems, for it is commonly assumed that the fuel is fully vaporized before it enters the chamber. The reason for this neglect is not only due to the inevitable endeavor to simplify an intrinsically complex reaction system but also because existing data on atomization are scanty and are believed to be not of direct application to liquid-fuel combustion.

The purpose of this paper is to present that part of the information on atomization which is most pertinent to spray combustion and to indicate gaps in existing knowledge. This task is appropriate at this juncture as it appears that mass transfer (evaporation) as a controlling mechanism has to be added to those hitherto considered, viz., reaction chemistry, fluid flow or mixing.

One of the most effective ways, but not the only way, of preparing a liquid fuel for vaporization is to atomize it. The function of the atomizing device, or the atomizer, is to disintegrate the liquid and to project and disperse the resulting drops in a preferred direction. The drops produced in the vicinity of the atomizer form the "initial spray," and they diminish in size during flight. Drops within the combustion chamber at any one instant form the "resident spray" whose drop sizes remain constant in time but whose drop size mean and size dispersion is different from that of the initial spray.

Mass Transfer from Sprays

The rate of vaporization depends on the area of contact between the liquid and gaseous surrounding,

Equation Symbols

A, A_s	= area	$[L^2]$
C_Q, C_v	= coefficient of discharge or velocity, respectively	$[-]$
ΔC	= mass concentration difference	$[M/L^3]$
d	= drop diameter	$[L]$
$D_0 D_M$	= diameter	$[L]$
D	= diffusion coefficient	$[L^2/T]$
F	= drag force	$[ML/T^2]$
FN	= flow-number	$[-]$
h	= mass transfer coefficient	$[L/T]$
I	= combustion intensity	$[Q/L^3T]$
k	= thermal conductivity	$[Q/LT\theta]$
L	= latent heat	$[Q/M]$
$\dot{m}'''$	= rate of mass transfer per unit volume	$[M/TL^3]$
MR	= mass ratio of air to liquid at 100 F	$[-]$
P	= pressure	$[M/LT^2]$
p_{gm}	= mean log partial pressure of gas	$[M/LT^2]$
p_{vs}	= saturation vapour pressure	$[M/LT^2]$
Δp	= pressure difference	$[M/LT^2]$
Re	= Reynolds number	$[-]$
Sc	= Sherwood number	$[-]$
So	= specific surface area	$[1/L]$
T	= temperature	$[\theta]$
U, V	= velocity	$[L/T]$
$\Delta\vartheta$	= fractional volume increment	$[-]$
Vi	= viscosity number	$[-]$
We	= Weber number	$[-]$
γ	= surface tension	$[M/T^2]$
λ	= evaporation constant	$[T/L^2]$
η	= absolute viscosity	$[M/LT]$
ν	= kinematic viscosity	$[L^2/T]$
ψ	= resistance coefficient	$[-]$
ρ	= density	$[M/L^3]$

* This paper contains the substance of a lecture delivered at the Liquid Fuel Combustion Conference held at Sheffield University in July 1960 under the direction of Prof. M. W. Thring, M.A., F.Inst.F., F.Inst.P., M.I.Chem.E. and published in the April 1961, *Journal of the Institute of Fuel*, 18 Devonshire St., Portland Place, London, W.1.

† High Speed Fluid Kinetics Laboratory, Department of Chemical Engineering, London.

the concentration gradient of the vapor, and the mass transfer coefficient, viz.

$$\dot{m}''' = -S_0 . \Delta C . h \qquad (1)$$

where

$\dot{m}'''$ = rate of mass transfer per unit volume
S_0 = specific surface area of liquid
ΔC = difference in mass concentration of vapor between interface and surrounding
h = mass transfer coefficient

To obtain a high rate, all three factors ought to be as high as possible.

Interfacial Area S_0

The specific area of the resident spray is given by the equation:

$$S_0 = 6\Sigma\frac{\Delta\bar{v}}{d} \qquad (2)$$

where $\Delta\bar{v}$, d = fractional volume within size group of

$$\text{diameters } d \pm \frac{\Delta d}{2}$$

Thus for a monosize spray, the smaller the diameter the larger the surface area (reciprocal relation). Further, for the more usual case of a polysize spray, the larger the number of drops of smaller size, the larger the surface area. The specific surface of the resident spray will be larger than that of the initial spray, but qualitatively the same reasoning applies to both sprays. The atomizer should therefore inject a large proportion of small drop into the combustion chamber in order to bring about a large vaporization rate.

The Concentration Gradient ΔC

This gradient of the vapor is proportional to the difference between the saturation vapor pressure of the liquid and the vapor pressure of the surroundings. The former increases with liquid temperature so that preheating the fuel is beneficial as it reduces the heating-up period before the maximum liquid temperature is reached. The heating-up period for drops is by no means negligible (1)*, but the period for rapidly moving sheets is unknown. The vapor pressure of the surroundings will increase downstream from the atomizer and will correspond to that of the lower limit of inflammability when ignition takes place. Thus, apart from preheating the fuel and assuring good mixing, little influence can be exercised on the concentration gradient ΔC.

The Mass Transfer Coefficient h

For a liquid drop in steady state mass transfer by diffusion, i.e., a stationary drop of static dimensions in quiescent surroundings,

$$h = \frac{2\bar{D}}{d}\frac{p_{gm}}{P} \qquad (3)$$

where

d = drop diameter
D = geometric mean diffusion coefficient (D) of the vapor near the surface and within the surroundings
p_{gm} = mean log partial pressure of the gas, i.e., the nondiffusing component, between surface and surroundings
P = total pressure of surroundings

Thus the *total* diffusional mass transfer rate of a drop is proportional to d and not to d^2 the surface area of the drop.

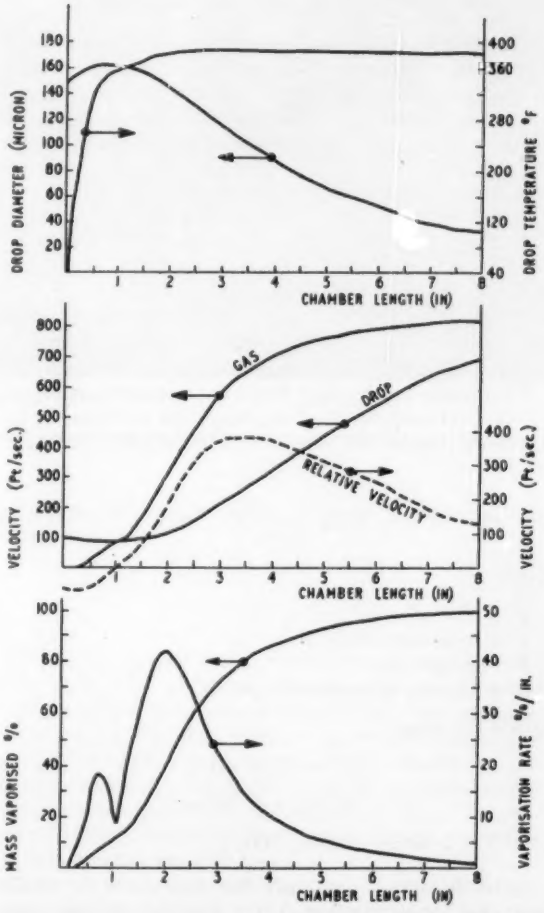
It follows from a solution of equation (1) for a single drop and using expression (3), that the surface area of the drop is a linear function of time and hence that the "life" of a drop is proportional to the square of its initial diameter. The proportionality constant λ is often referred to as the evaporation constant. It is given by the expression

$$\lambda = \frac{\rho_l L}{8k\Delta T} \qquad (4)$$

where

L = latent heat of liquid
ρ_l = density of liquid
k = thermal conductivity of surroundings
ΔT = difference in temperature between drop and surroundings

Equation (4) is applicable only where diffusional



Redrawn by courtesy of NASA, Washington

Fig. 1—Calculated history of a fuel drop in a one-dimensional combustion system

* Numbers in parentheses refer to similary numbered entries in References at end of article.

transfer takes place. Various values of λ are summarized in reference (2).

The mass transfer per unit volume of the spray for diffusional transfer is thus given by

$$\dot{m}''' \propto \Sigma \frac{\Delta \bar{v}}{d^2} \tag{5}$$

For drops in relative motion, mass transfer by convection takes place which depends on the diameter and relative velocity of the drop and various transport properties. However, within the laminar regime of flow (e.g., drops of 10 μ at a relative velocity of about 10 fps) the above relations are still applicable; outside this regime, the mass transfer coefficient can be expressed in dimensionless form, viz.,

$$Sh \frac{p_{gm}}{P} = 2 + Sc^{1/3}\mathrm{Re}^{1/2} \tag{6}$$

where

Sh = Sherwood number $hd/\bar{D}$
a = a constant given as 0.6[3]
Sc = Schmidt number of surroundings $\nu_g/\bar{D}$
ν_g = kinematic viscosity of surroundings
Re = Reynolds number of system ud/ν_g
u = relative velocity (drop: surroundings)

There is indeed nothing known about the entrainment properties of sprays and calculations are usually based on the entrainment of jets. Velocity, temperature and composition profiles within the chamber have to be calculated or experimentally determined so that together with a knowledge of the drop velocity, the relative velocity and hence the Reynolds number can be obtained.

Initial drop velocities are assessed from the operating conditions of the atomizer (see "*The Instability of Sheets*," below) and the change in drop velocity can be calculated from a knowledge of the drag on the drops. Information on steady state drag on drops is invalid because the drops are exposed to a changing relative velocity, and mass transfer and often burning is taking place at their surface.

For rapidly accelerating drops in saturated airstreams, Ingebo (4) has shown that the drag force is related to the Reynolds number by means of a resistance coefficient, viz.,

$$\psi = \frac{13.5}{\mathrm{Re}^{0.84}} \tag{7}$$

where

$\psi = F/{}^1/_8 d^2 \pi \rho_g u^2$
ψ = resistance coefficient,
F = drag force,
ρ_g = density of surroundings,

within the range

$$6 < \mathrm{Re} < 400$$

$$20\ \mu < d < 120\ \mu$$

$$\text{acceleration} \lesssim 2000\ g$$

Thus the drag in unsteady flow appears to be smaller than that for steady flow. It is doubtful whether equation (7) can be applied outside the experimental range for which it was obtained, particularly whether it is applicable to decelerating drops. In general, drops will reach their terminal velocity relatively quickly and during the decelerating period there is considerable evaporation particularly for large drops (5).

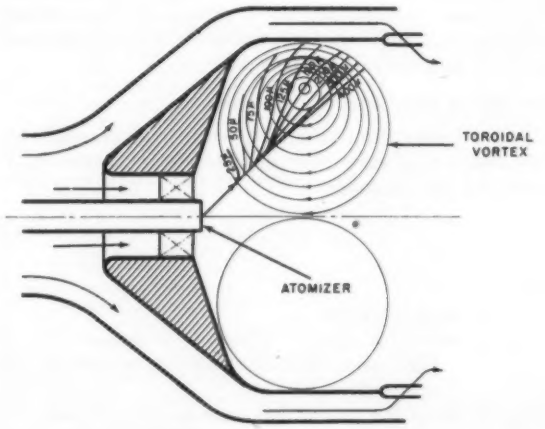
The drag of drops undergoing mass transfer and particularly burning is also smaller than for conditions of no transfer. In fact, drops travel faster when there is flame associated with them. This is a well known effect first observed with flame throwers whose range is greatly increased if the jet burns fiercely. For drops, the effect is caused by increased mass transfer in the wake where the flame is anchored; this gives a propelling thrust to the drop thereby reducing the overall drag. The effect has been experimentally investigated by Lubanski (6) and Khudyakov (7) for large particles between 16–38 mm. The former worked with spheres soaked in fuel and the latter with drops of fuel in air, both covering a range of Reynolds numbers of 2000 to 25,500.

Application of Treatment

For the application of the above general treatment to the specific conditions of a liquid fuel spray undergoing mass transfer for combustion, the following considerations might help:

(*a*) In some combustion systems, particularly those operating under subatmospheric densities, the saturation vapor pressure of the liquid is not small compared with the total pressure and hence the fractional concentration of the diffusing component is large. Corrections for this condition can be made to Fick's law of diffusion which is expressed in equation (1), but they are in fact rarely attempted and the effect cannot therefore be quantitatively assessed. More important is the increase in the partial vapor pressure of the surroundings from the assumed value of zero because of the presence of the many evaporating nuclei in a liquid spray. This effect can be large and it will reduce the mass transfer rate as compared with that of single drops in infinite surroundings (8).

(*b*) The drops take a finite time to reach a quasi-steady temperature. This heating-up period can occupy a considerable proportion of the total life time of small drops and a convenient way of allowing for it in calculations is given in the paper under reference (1).



By courtesy of The Institution of Mechanical Engineers

Fig. 2—Calculated paths of drops through a toroidal vortex

$\Delta p = 100$ psi $\Delta p = 125$ psi $\Delta p = 800$ psi

Fig. 3A—Instabilities of liquid sheets—the row $3a_1$, a_2, a_3 represent sheets of pure liquid under the pressures shown and discharging into the atmosphere

$\Delta p = 100$ psi $\Delta p = 125$ psi $\Delta p = 800$ psi

Fig. 3B—Instabilities of liquid sheets—the row $3b_1$, b_2, b_3 represent sheets of pure liquid under the pressures shown discharging into a vacuum

(c) The temperature of the evaporating liquid is taken as the adiabatic saturation temperature of the system, or the boiling point of the liquid. This is only true for stationary drops receiving all the heat for evaporation by conduction. In combustion, the temperature difference from surface of drop to surroundings is very large and the effect of mass transfer on heat transfer should be allowed; i.e., the heat is not only given to the drop for evaporation but also to the vapor. This latter amount can often be very great and estimates of it can be made only under special circumstances (9).

(d) Where temperature gradients are large, there is a considerable movement of the nondiffusing component away from the drop in order to maintain the partial pressure of the diffusing vapor, and the flow affects evaporation. The effect is fully allowed for by the term $(p_{gm}/P$ in equation (3). For the case of convective mass transfer, the corresponding term has been inserted in equation (6) by analogy. Assuming the surroundings to be free of vapor and the partial vapor pressure at the surface to be the saturation vapor pressure p_{vs}, it follows that

$$\frac{p_{gm}}{P} = \frac{p_{vs}}{P \ln \dfrac{P}{P - P_{vs}}} \tag{8}$$

(e) Radiative heat transfer may play a large part in combustion and although this transfer to a single combustion drop in a nonabsorbing atmosphere has been investigated (10), the problem becomes theoretically quite intractable for sprays in heat absorbing and reflecting systems and only empirical relations under noncombustion conditions are available (11). In general, the effect of radiative heat transfer in spray systems is to reduce mass transfer rates.

These considerations of mass, heat and momentum transfer can be used to calculate the histories of vaporizing drops for given environmental conditions and a knowledge of the size of the initial drops and their velocity.

The one-dimensional model has been treated by Spalding (12a) and by Priem *et al.* (12b). Fig. 1 (12c) shows the history of a single drop in a rocket chamber assuming that it is not shattered in transit. The liquid is *n*-heptane initially at 40 F temp., 150 fps injection velocity, and of 150 μ drop diameter. The atmosphere is pure oxygen at 2780 K, 300 psia initially at rest and finally moving at 800 fps velocity. This treatment for single drops can be extended to sprays, and since combustion in a rocket chamber is predominantly a one-dimensional process (changes take place in axial direction only), the result from the above model can be shown to be well correlated with those obtained from some practical systems in which the initial drop size is known and in which mass transfer can be considered to be combustion rate controlling: The chamber length for any required degree of completion of vaporization can thus be calculated from a knowledge of the performance of the atomizer in terms of drop size and injection velocity.

A two-dimensional model relevant to air-aspirated combustion chambers was treated by Clarke (13). An idealized toroidal vortex was considered, and the path and life of evaporating drops of different sizes impinging on the vortex from one direction was calculated. Such a system can be likened to the impingement of drops from a swirl atomizer on to the vortex in the primary zone of the gas-turbine combustion chamber. The resulting drop histories within the vortex only are shown in Fig. 2 (13), where the locus of drops of given initial size is plotted, the length of the paths inside the vortex indicating the life of the respective drop. (No operating conditions are stated in reference (13).) It is seen that below a limiting initial size, viz., approximately 80 μ, all the drops evaporate within the vortex and that large drops traverse the vortex almost unhindered.

The generalized case was treated by Probert (14) who showed that, assuming diffusional mass transfer to be rate controlling, the intensity of combustion, I (rate of heat release per unit combustion space), can be related to the mean diameter of the initial spray. He has shown that for a spray of one particular drop size distribution and initial mean size d_0

$$I \propto \frac{1}{d_0^2} \tag{9}$$

and that the degree of size dispersion affects the total life time of the spray.

These three examples suffice to show that in systems which are mass transfer controlled (viz. systems where the rate of chemical reaction is faster than the rate of vaporization, and mixing is perfect), the performance of the atomizer is expressed by drop size and drop velocity affects the combustion performance, particularly combustion intensity and combustion space available to achieve completion of combustion. Although the smallest drop size is required to achieve a high combustion intensity, the combustion space theoretically required is far too small to achieve good mixing. In practice, the space has to be larger and larger drops have to be produced with a large enough momentum to achieve satisfactory mixing.

Thus the atomizer is required to produce a range of drop sizes. Small drops give large vaporization rates per unit volume and are necessary to initiate the flame for only drops below a certain threshold size behave as a premixed flame (15) where simple gaseous flame propagation is possible.

These small drops sustain the flame which, in turn, provides sufficient heat so that the large drops can vaporize completely within the chamber. Vaporization of large drops, however, cools the flame so that small drops must be present in sufficient quantity. The relative quantities involved, i.e., a satisfactory drop size distribution, taking all these factors into account cannot, as yet, be predicted from theory, although partial requirements such as mean drop size or maximum or minimum drop size can be met as indicated above.

The Formation of Drops

Liquid disintegration by means of atomizers takes place in stages. Each stage is a vibratory process so that the cloud of drops moves into the flame not uniformly but intermittently. In most common practical cases, the drops are formed from liquid sheets and atomizing devices are primarily devices for filming a liquid and for disintegrating the resulting sheet of liquid. Where no secondary fluid is employed for disintegration, the inherent instability of these sheets gives rise to the production of drops by the formation of unstable threads. The drops by themselves may be unstable, i.e., they may shatter of coalesce.

This instability in the process of formation of drops is of particular importance in combustion and may be one of the contributory causes of some types of combustion oscillation. For this reason, they will be described in some detail below.

The Instability of Sheets

Rapidly moving liquid sheets from pressure atomizers of the fan-spray type have been studied predominantly because of experimental convenience, but there is no reason to think that their properties are not common to all types of sheets from atomizers. Sheets are thinning out in the direction of flow because their surface area increases. Their thickness at the point of disintegration is of the order of microns (16). For pressure atomizers, the velocity of the sheet is constant in the direction of flow and given by

$$V = C_v \sqrt{\frac{2g\Delta p}{\rho_l}} \tag{10}$$

where

V = velocity of sheet
C_v = discharge coefficient
Δp = pressure difference across atomizer (for discharge to atmosphere Δp is the injection pressure)
ρ_l = density of liquid

Hence, the velocity with which the drops are projected into the flame is the same for all drop sizes. For a heavy fuel oil of density 0.89 g/cm^3 injected at a pressure of 100 psi from a pressure nozzle (C_v — 1), this velocity is 130 fps.

The sheets display three types of instabilities which can be seen in Fig. 3. The lower row shows sheets of pure liquid discharging into vacuum at increasing injection pressures, and the upper row shows sheets at corresponding pressures but discharging into atmosphere.

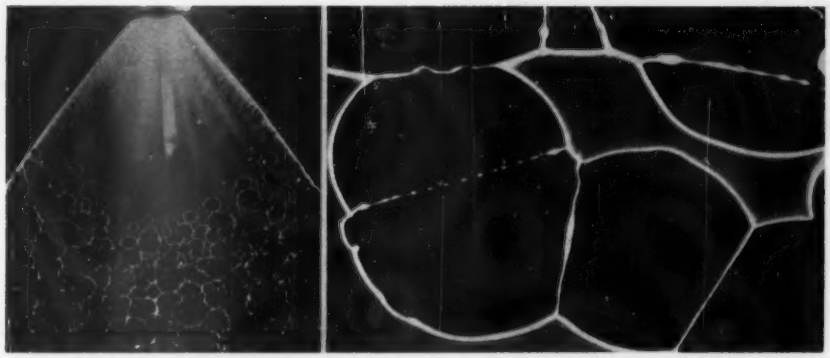


Fig. 4—Perforated sheet disintegration from fan spray nozzle with a liquid containing insoluble and unwettable impurities, a, left, and these perforations enlarged, b, right

If the effect of ambient atmosphere on the stability of the sheet is removed by spraying into vacuum, the instabilities due to liquid flow only are revealed. There are two types of such instabilities, viz., the formation of perforations and turbulent flow.

The perforations are clearly visible in the placid sheets in vacuum at the lower injection pressures. They are not, however, confined to such conditions but also occur with liquids containing insoluble and unwettable impurities even when sprayed into atmospheric pressure, as shown in Fig. 4*a* for a water:oil emulsion. The perforations expand and lead to disintegration of the sheet by coalescence and the formation of threads which vibrate and disintegrate into drops. An analytical treatment of the movements of these perforations is given in reference (17). In Fig. 4*b* is shown an enlarged portion of such a perforated sheet. Where a thread is formed, monosize drops result whose size can be calculated from Rayleigh's theory of thread disintegration. However, as can be seen from the photographs, not only clear threads but entangled threads and small islands of liquid disintegrate and these give rise to irregular drop formation and hence the wide variation in drop size of a polysize spray results. The causes of these perforations are either penetration of the sheet by particles from within the liquid or from without, or vibrations in the nozzle itself. For a sheet from a fan spray nozzle, these vibrations have been measured and found to be 10 milocycles per second (18). Heidman (19) measured those occurring in sheets from impinging jet nozzles and found them to be within 1 to 3.5 kc. It is of interest to note that the screeching in rocket motors occurs at a frequency of this order, the highest observed frequency being 20 kc.

Whether turbulent flow of the sheet, as shown in Fig. $3b_3$, is in instability which leads to a distinctly different drop formation has not yet been established because it is difficult to obtain turbulent sheets without perforations.

The third type of instability occurs as a result of the influence of ambient atmosphere and is clearly shown in Fig. $3a_{1,\,2,\,3}$. It leads to waves of exponential growth which bring about disintegration of the sheet. This type of instability has been analyzed in reference (17). The instabilities due to growth of perforations or growth of waves lead to different drop sizes of the resulting spray cloud.

Instability of Drops

Drops traveling in relative motion through a gaseous medium and undergoing evaporation are not necessarily spherical nor is the liquid within the drop stationary. Deformations, oscillations and internal circulation in drops of sprays under combustion conditions in a furnace have a negligible effect on disintegration, except when they lead to the splitting of drops (shatter) as a result of impact with gas streams. This instability phenomenon as well as the collision of drops (coalescence) is particularly relevant to sprays under combustion conditions. The relative velocity of the drop and the gaseous medium is one of the primary quantities affecting the existence of shatter or coalescence but, in practice, it is the most difficult one to measure or assess. Hence, estimation of the extent to which these processes cause disintegration in sprays is only possible in special circumstances.

The Shatter of Drops.[1] In atomization, the forces which control shatter of drops dispersed in a gaseous medium are threefold: external dynamic forces which may bring about a deformation of the drop and produce internal forces, and surface tension forces which counteract the deformation. For a drop in relative motion in a uniform gaseous stream, the forces can be expressed in two dimensional groups, viz.,

Weber group (We, the Weber number)

$$\mathrm{We} = \frac{d}{\gamma} \times \text{dynamic external pressure} = \frac{\rho_g u^2 d}{\gamma}$$

Viscosity group (Vi, the viscosity number)

$$Vi = \frac{\eta_l}{\sqrt{\rho_l \gamma d}}$$

where

- u = maximum relative velocity between the drop and surroundings
- η_l = absolute viscosity of liquid
- ρ_g ρ_l = density of gas and liquid resp.
- γ = interfacial tension
- d = drop diameter

The greater the Weber number of a system, We, the greater the deformation of the drop until at a critical

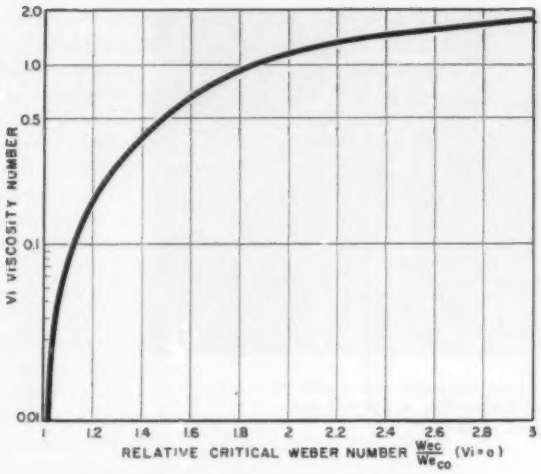


Fig. 5—Effect of viscosity on critical Weber number

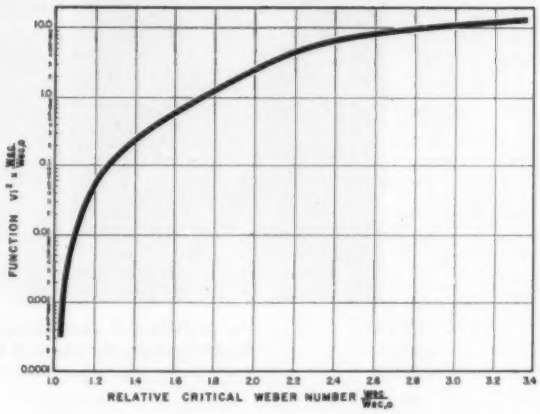


Fig. 6—Effect of viscosity on critical Weber number (correlation)

Weber number We_c ($We > We_c$) shatter of the drop occurs. This critical Weber number depends not only on the magnitude of the viscosity number, Vi, which primarily accounts for the effect of viscosity of the liquid but also whether the drop is falling in stagnant gas or is in steady flow.

For an inviscid liquid:
$We_{c,0} \approx 13$ in steady flow
$We_{c,0} \approx 22$ for the falling drop
where $We_{c,0}$ is the critical Weber number for $Vi = 0$.

For a viscous liquid ($Vi \gtrsim 0.01$), the critical Weber number depends on the viscosity number as shown in Fig. 5 which is based on experimental results of drops in steady flow (20).

The mode of disintegration under combustion conditions, where the Weber number is never very much greater than the critical value, has been called the "bag formation" break up (21). At steady flow exposure, the drop deforms into a lens, the convex part facing downstream, until a bag is blown out of the center supported on a ring. The bag consists of a thin liquid film which eventually becomes unstable and disintegrates into a mass of fine drops, while the ring is a toroidal thread which becomes unstable and disintegrates into few relatively large drops.

Calculations to find the critical diameter above which drop shatter will take place require a knowledge of the type of exposure and are usually based on steady flow which results in a minimum critical diameter. Fig. 5 has been transposed into the correlation shown in Fig. 6 where the function $Vi^2 \times (We_c/We_{c,0})$ (which is independent of d) is plotted versus $We_c/We_{c,0}$.

By means of this correlation, it is possible to calculate critical diameters of drops above which shatter will occur on impingement with a parallel stream of gas. Operating conditions of four representative fuels have been chosen under impingement with air at room temperature as it might be used for twin-fluid atomization. The relative velocities for which the calculations were made are fractions of the sonic velocity, viz. 1120 fps and steady flow exposure has been assumed. The physical properties of the fuel and the results are given in Table 1.

It is seen that in shatter, drops of conventional fuels behave alike although their jet viscosities are considerably different.

The conditions in the hot combustion chamber can be analyzed similarly, provided the assumption is justified that external dynamic forces are responsible for the deformation of the drop and that viscous forces in the hot surroundings are not predominant.

The drops reach approximately their boiling tempera-

TABLE 1—CRITICAL DIAMETERS FOR SHATTER ON IMPINGEMENT WITH COLD AIR

Properties of Fuel		Heavy Fuel Oil	Medium Fuel Oil	Gas Oil	Kerosene
Injection temperature, C		105	83	15	20
Liquid density, g/cm³		0.894	0.88	0.85	0.80
Kinematic viscosity, stokes		0.15	0.094	0.070	0.0204
Surface tension, dynes/cm		20	21	24	26
Critical Diameter (μ)					
Impingement relative velocity	fps				
Sonic	1120	4.2	3.7	3.6	2.9
1/2 sonic	560	13	12	12	11
1/4 sonic	280	43	40	42	40
1/8 sonic	140	146	152	157	155

TABLE 2—CRITICAL DIAMETERS FOR SHATTER ON IMPINGEMENT WITH HOT RECIRCULATING GASES

Properties of Fuel		Heavy Fuel Oil	Medium Fuel Oil	Gas Oil	Kerosene
Temperature, C		240	220	170	140
Liquid density, g/cm³		0.806	0.79	0.746	0.713
Kinematic viscosity, stokes		0.017	0.012	0.007	0.005
Surface tension, dynes/cm		9	12	14	16
Critical Diameter (μ)					
Impingement relative velocity	fps				
	1120	5.4	6.7	7.4	8.2
	560	20	26	29	32
	280	77	99	112	128
	140	288	388	448	512

TABLE 3—CLASSIFICATION OF ATOMIZERS

Pressure Energy Used for Pressure Atomizers	Centrifugal Energy Used for Rotary Atomizers	Gaseous Energy Used for Twin Fluid or Blast Atomizers Internal Mixers or External Mixers
Fan shaped sprays:	Spinning cups ←	→ L.P. atomizers: Low pressure (5–35 in. w.g.) Gas:liquid mass ratio above 10
Fan spray nozzles		
Impact nozzles	Average diameter: 2 in.	
Impinging jet nozzles	Average rotation: 4,000 r.p.m.	
Solid surface impact nozzles	Average flow rate: 400 lb/h	→ M.P. atomizers: Medium pressure (<1 atm) Gas:liquid mass ratio 0.2–1
Deflector nozzles		
Conical shaped sprays:		→ H.P. atomizers: High pressure (>1 atm) Gas:liquid mass ratio <0.5
Swirl spray nozzles ←		
Hollow cone		
Drowned cone		
Divergent pintle nozzles		

ture at a short distance from the atomizer and are exposed to hot circulating gases. The critical diameters under such conditions are calculated for a chamber temperature of 1400 C.

From comparison with Table 1 it is seen that once drops have reached their maximum evaporation temperature, they are more stable and only shatter when they are approximately 1 to 3 times as big as under cold conditions.

Coalescence of Drops. Very little analytical work has been carried out on this process although repeated references are being made to the existence of coalescence because the drop size of sprays have been observed to increase with distance from the nozzle. Such coalescence has been ascribed to the great concentration of drops in a spray (distance between drops $< 10d$) even at distances away from the liquid sheet where the drops would travel at different velocities. Because of the method of disintegration of the liquid sheet discussed above drops from one thread would be expected to travel fairly concurrently, but they may colloid with drops produced from another thread released from another portion of a wavy sheet. Much is known about the aerodynamic capture of drops by other drops from studies in meteorology, but no application of this work to sprays has been forthcoming. Coalescence of drops could, however, be due to combustion oscillations in the chamber and qualitative observations on this phenomenon have been made (22). Coalescence occurs only within a narrow range of relative velocities produced by oscillations because, at lower velocities, drops have been observed to rebound from each other and, at higher ones, they would shatter.

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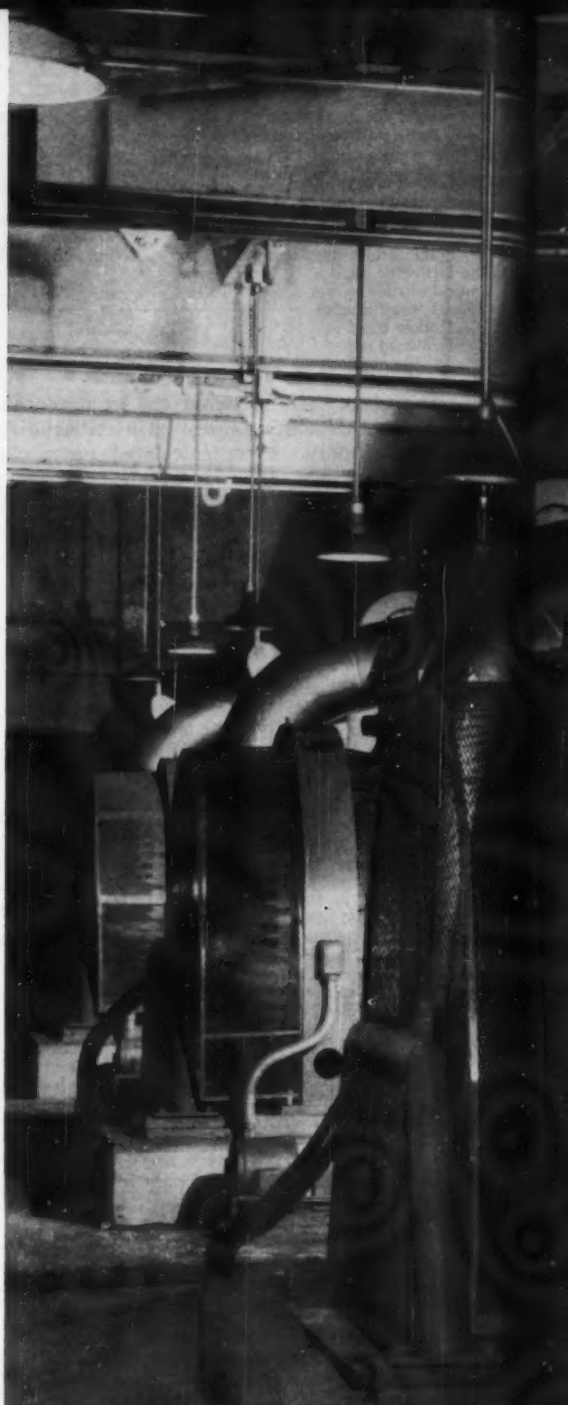

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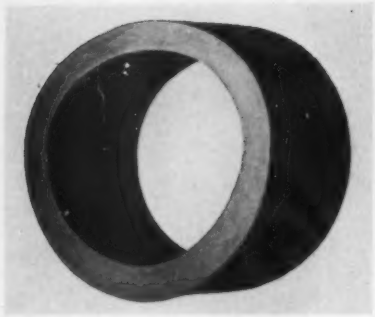

Fig. 20—Failure in tube caused by notch formed along tube inside by tubedrawing die

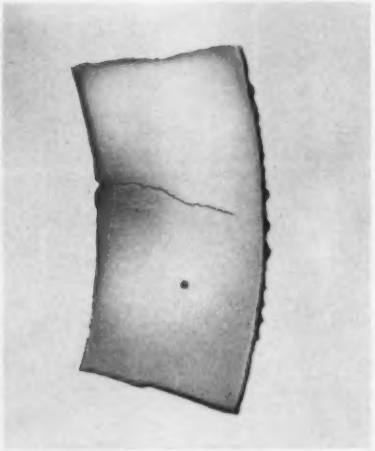

Fig. 20 A.—The bove failure Fig. 20 is here shown in anlargment

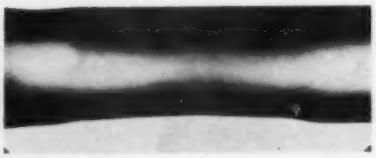

Fig. 21—Radiograph of tube section, above, shows deep score grooves in tube inside surface

Fig. 22—Blow-out failure of overheated boiler tube along deep score groove

Detecting Service Failures in Power Plants*

By HELMUT THIELSCH†

Grinnell Company, Inc.

The gradual, silent collapse of the pressure members of the typical steam-power cycle has defied the otherwise reliable shift-by-shift, watch engineer's visual appraisal of equipment performance. Here is a two-part roundup of the newer inspection techniques now being perfected and a series of examples isolating some of the major failures

Part II-Examples

INTELLIGENT periodic inspection has prevented many actual service failures by detecting cracking, excessive corrosion or other defect conditions in their early stages of development or propagation. However, there are also many instances where failures across the metal section have actually occurred and have necessitated a costly shutdown. Extensive experience with service failure investigations has shown that whereas the majority of these service failures could have been detected by nondestructive testing or destructive sampling techniques, some potentially very hazardous conditions

* Presented during 1960 National Fall Meeting of the Society for Nondestructive Testing, Philadelphia, Pa., October 19, 1960.
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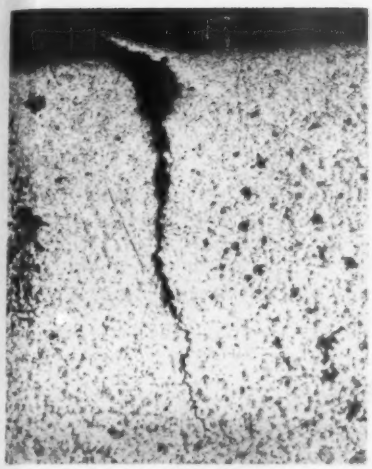

Fig. 23—Start of stress corrosion cracking from groove in old bent boiler tubing not subsequently stress relieved

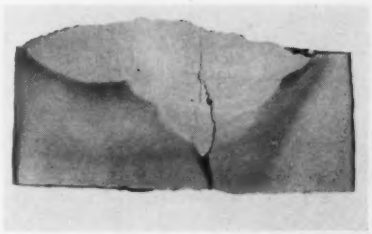

Fig. 24—Stress corrosion cracking failure originating in lack-of-penetration in weld in boiler feed piping system

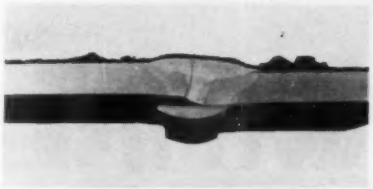

Fig. 25—Stress corrosion cracking failure in process steam piping originating at notches formed by improperly fitting backing ring

Fig. 26—X-ray radiograph of weld containing lack-of-penetration stress corrosion cracking illustrated in Fig. 24

would have missed detection by normal inspection techniques.

A discussion of the various types of service failures encountered in normal power plant operation would involve thousands of examples. Therefore, only a few of the more common and potentially hazardous types of failures will be discussed here.

Notches

The presence of notches frequently is one of the major factors permitting initiation of a crack and gradual propagation under thermal fatigue and shock conditions. Fig. 20 illustrates cracking starting at the tube ID from a deep groove remaining from the pipe extruding operation. Radiography with Iridium sources, Fig. 21, or ultrasonic inspection are occasionally employed to determine the presence and depths of score grooves in tubing. Deep score grooves may reduce the creep strength in boiler tubing and enhance failure particularly where some overheating may be involved, Fig. 22.

The notch effect formed by score grooves is particularly hazardous in cold bent boiler tubing not subsequently stress relieved when exposed to environments considered stress corrosive, Fig. 23. Where stress corrosion cracking is suspected, ultrasonic inspection techniques and, occasionally, radiographic inspection with Iridium 192 sources should be used to confirm the presence or absence of cracking in the scored tubing.

Severe weld notches representing lack of penetration in boiler feed piping and in low pressure steam piping are illustrated in Figs. 24 and 25 respectively. Since this piping is not normally radiographed, these conditions were not detected until the actual failure occurred. Radiographic examination, however, would have detected the inherently hazardous notch condition of the original welds, Fig. 26.

Welds in steam piping susceptible to stress corrosion may also crack as a result of slight lack of penetration in the root of the weld, even where backing rings are used, Fig. 27. Careful interpretation of the original radiograph should have detected this potentially hazardous condition. Design notches can be similarly hazardous. Sharp corners on the inside of turbine casings may frequently cause initiation of cracking, Fig. 28. Normally, these cracks propagate gradually. Although the larger cracks can be seen visually, the finer cracks are detected best by either dye penetrant inspection or magnetic fluorescent particle inspection techniques.

Cracks

Cracks may also be produced in the material as result of forming, fabrication, welding or heat treatment. Such cracks represent extremely severe notches and are usually considered extremely hazardous.

Fig. 20 illustrates very fine shatter cracks near the surface of pipe hanger springs. These cracks were caused by improper heat treatment. In several instances, the springs failed even under no-load conditions in the power plant, Fig. 30. Fluorescent magnetic particle inspection was used to determine the presence of cracks in the springs.

Fatigue Failures

Potential fatigue failures are among the most difficult to predict. Fig. 31 illustrates a 1-in. wide crack on the outside of a main steam cross-over lead in service at a temperature of 950 F. Radiography with an Iridium 192 source showed this crack to be $4^1/_2$-in. long at the inside surface of the pipe. Moreover, several additional cracks were observed which had not quite traversed the wall thickness, Fig. 32. Only the three most severe cracks were repaired immediately during the shutdown, Fig. 33, because the plant had to be returned to normal operation as soon as possible. Prior to a decision on the replacement of the pipe section, other areas in the cross-over lead that were considered potential locations for cracking were examined for cracking by radiographic techniques.

A similar cracking failure that resulted in a steam leak is illustrated in Fig. 34.

Fig. 27—Stress corrosion cracking in "miner" lack-of penetration area underneath of backing ring from which a section has been removed

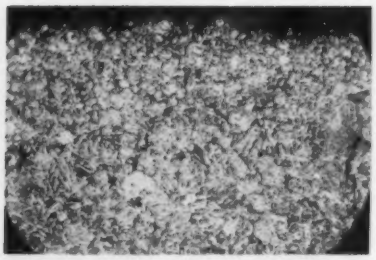

Fig. 29—Fine "shatter" cracks in surface of alloy steel springs caused by improper heat treatment

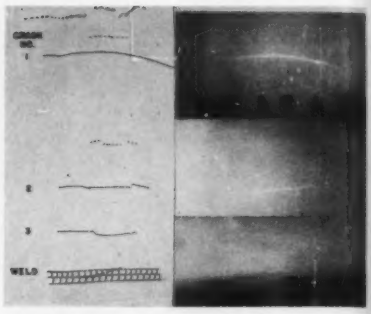

Fig. 32—Iridium 192 radiograph revealing extent of cracking in pipe section shown in Fig. 31

Fig. 28—Ground out cracks at inside of turbine casing originating at sharp corners

Fig. 30—Hanger spring failure caused by fine shatter cracks

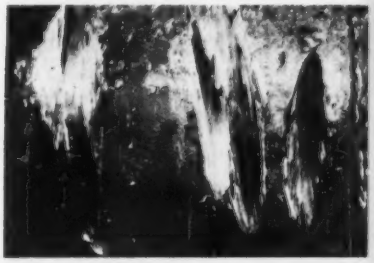

Fig. 33—Rough grinding out of three cracks prior to finish grinding and magnetic particle examination to determine if full length of cracks has been properly prepared for repair welding

Fig. 31—One inch long crack in outside of high-temperature steam pipe

Corrosion

A corrosion failure in a feedwater piping system is illustrated in Fig. 35. The cause was diagnosed as excessive local heating with an oxyacetylene torch—probably in preparation for cutting. Periodic ultrasonic inspection would have detected the gradually developing failure during a normal shutdown period.

A similar potential failure in a boiler feed pipe section was detected by ultrasonic inspection. Here the pipe producer had by excessive shot blasting abraded a $1^1/_4$ in. deep cavity into the $1^1/_2$ in. wall pipe from the inside, Fig. 36.

A corrosion failure in a sulphuric acid line of seamless A-106 pipe is illustrated in Fig. 37. An ultrasonic spot check during a routine shutdown could have prevented this failure.

Metallurgical "Notches"

Metallurgical "notches" usually represent brittle conditions in the metal which have not yet resulted in cracking. In this condition it is generally impossible to detect the existing or developing hazardous condition by non-destructive means. In power plant service the development of several types of metallurgical notches are frequently associated with metallurgical changes occurring in carbon or low-alloy steel at temperatures over 800 F. However, metallurgical notches can also have been introduced by the original fabricating, welding or heat treating operation. In many instances these metallurgical notches result in gradual cracking and may then be detected by the proper non-destructive test.

Examples of potential failures involve dissimilar metal joints as between carbon and carbon $^1/_2$ per cent molybdenum steels, Fig. 38, and between carbon-molybdenum and 1 Cr - $^1/_2$ Mo low alloy steels, Fig. 39.

Surface decarburization or carburization, Fig. 40, has also resulted in brittle condition ultimately permitting cracking failures, Fig. 41.

Most hazardous failures have been in carbon-molybdenum steels where graphitization has occurred adjacent to weld deposits. Where graphite formation progresses to "severe" degree, Fig. 42, extreme brittleness results (5). A bend test across the embrittled area would fail upon bending only a few degrees Fig. 43, whereas the unembrittled steels could be bent to 180 deg. without failing. Although cracking frequently accompanies embrittlement and can then be detected

Fig. 34—Steam leak as result of cracking in steam pipe

Fig. 36—$1^1/_4$-in. deep cavity at inside of 16-in. OD × $1^1/_2$-in. wall steel pipe

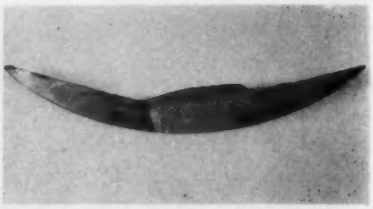

Fig. 38—Cracking in carbon steel repair weld adjacent to carbon-$^1/_2$ per cent molybdenum steel field weld joining the carbon-$^1/_2$ per cent molybdenum steel valve body to carbon-$^1/_2$ per cent molybdenum steel pipe

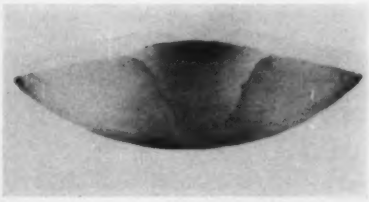

Fig. 39—Cracking in carbon-$^1/_2$ per cent molybdenum steel weld deposit made in 1 per cent Cr-$^1/_2$ per cent Mo steel base metal (X1 above, X10 below)

Fig. 35—Corrosion failure in boiler feedwater pipe section

Fig. 37—Corrosion failure in cold bent seamless carbon steel pipe section carrying sulphuric acid

by non-destructive tests, occasionally a severe mechanical or thermal shock, as may occur during start-up operations, has caused sudden rupture—generally of disastrous consequences. To date none of the major non-destructive tests have been successful in service inspection for detecting the embrittlement caused by graphitization.

Incorrect Base Metals

A mix-up in materials, frequently the result of improper identification by the steel supplier, has also led to a number of service failures. For example, failures have occurred where welded A-53 pipe has been substituted for seamless A-106 pipe in high temperature service. Welded A-53 pipe frequently contains a notch along the weld seam on the inside of the pipe, Fig. 44, though the OD is sufficiently smooth to make the differentiation between seamless and seam welded pipe extremely difficult. The substitution of carbon steel for low chromium-molybdenum alloy steel at elevated temperatures has also led to a number of failures.

Although inspection is available for separating materials by means of instruments measuring magnetic permeability or electric resistivity, or by portable spectroscopes, relatively little use is being made of these techniques at the present time.

Casting Defects

Shrinkage cavities in valve bodies, fittings, or turbine casings may also lead to service failures. Although their presence can be detected by ultrasonic means, radiographic techniques are usually necessary to determine if they are potentially hazardous.

Cracking that resulted from shrinkage cavities in a turbine casing is illustrated in Fig. 45.

Summary

Many other types of failures have occurred in power plants; not one of the engineering materials used is immune.

One disturbing element is that the material, fabrication and welding quality are being reduced by many fabricators in order to meet competition. Therefore, a correspondingly increasing number of hazardous conditions are likely to be present in the newer power plants. Frequently, inspection is also reduced on the originally installed equipment to cut costs further.

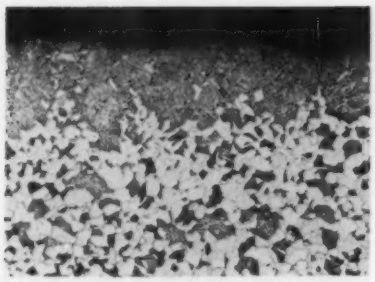

Fig. 40—Surface carburization revealed by metallographic examination of microstructure in $1^1/_4$ per cent Cr–1 per cent Mo alloy steel fitting. (X100)

Fig. 41—Very low ductility in carburized $1^1/_4$ per cent Cr–$^1/_2$ per cent Mo base metal surface along weld seam resulting in cracking during slight bending of weld joint made by properly preheating and stress relieving

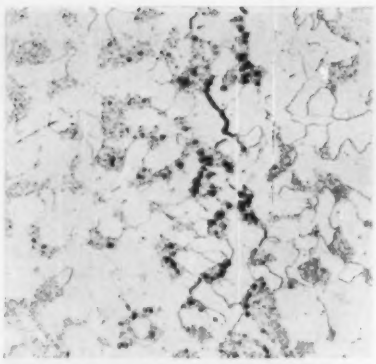

Fig. 42—Photomicrograph illustrating severe degree of graphitization in carbon-$^1/_2$ per cent molybdenum base metal (X100)

Fig. 43—Cracking in bend test specimens upon bending by 5 to 15 degrees indicating severe embrittlement caused by graphite formation in heataffected zone of carbon-$^1/_2$ per cent molybdenum base metal

Fig. 44—Notch formed by seam weld along inside surface of some steel piping materials. Outside surface usually is very smooth so that such pipe frequently appears as "seamless" (X7$^1/_2$)

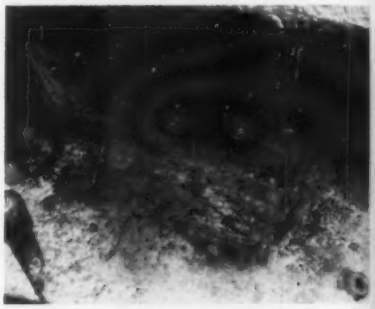

Fig. 45—Cracking in heavy turbine casing made of carbon-$^1/_2$ per cent molybdenum steel

Where the inspection is performed on a lump sum basis, the commercial laboratory is frequently forced to employ the fastest techniques and films, thereby producing results providing the least contrast and missing many inherently defective conditions. Thus, a severe notch, lack-of-penetration, or small crack may remain which in time will be propagated into a service failure. Since operating conditions are becoming more severe, increasing failures can be expected.

Although to date the majority of failures have occurred in carbon and carbon-molybdenum steel material, the low chromium-molybdenum steels and stainless steel materials that are now being used in the newer power plants are also likely to fail. This is particularly true when the newer power plants are no longer operated continuously, but experience week-end or other periodic shutdowns that result in thermal and mechanical fatigue of many of the materials involved. Already a number of failures have been observed in the chromium-molybdenum alloy steel and stainless steel materials used in power plants.

When these power plants have been operated for over 5 to 8 years, periodic review of entire installations by qualified and experienced inspection personnel becomes advisable. Only extensive experience should serve as the basis for recommendations as to which materials, piping components, equipment should be inspected and by what techniques during normal shutdown periods. The recommendation must also include an understanding of the materials involved, the effects of weld joint preparation, various welding techniques, fabricating and heat treating methods and the effects of service.

Although many commercial testing laboratories offer inspection service, only very few are qualified for the interpretive scientific approach to non-destructive testing. Where this is done, non-destructive testing is no longer an art but takes its place among the major engineering professions.

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By

W. B. KINCAID†
Carolina Power & Light Co.
and
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Ebasco Services, Inc.

Putting The Digital Computer To Work* At The H. B. Robinson Plant

Introduction

THE evolution of an original concept to engineering achievement usually follows a sequence of three engineering steps—*establish feasibility, justify cost, accomplish*. It was just a few years ago that a MARC (Monitoring and Results Computer) system such as that recently installed at the H. B. Robinson plant of Carolina Power & Light Company was no more than an idea. The ever-increasing acceptance of these computer systems suggests that the first two steps have been successfully taken.

This brings us to step three—*accomplish* or "Put the concept to work." At present, there is a concentrated engineering effort being undertaken to complete this last step. More and more of us are becoming a part of this effort.

What is involved in putting a MARC system to work? In this paper we will attempt to answer this question as it applies to the H. B. Robinson plant. It should be pointed out that there remain areas where work has not yet been satisfactorily completed; some because of computer limitations and others because of the need for further knowledge about plant dynamic characteristics and measuring techniques.

The engineering effort required for putting the MARC system to work can be divided into two distinct parts; design and system engineering, and field engineering.

The design and system engineering includes:

1) Digital computer, its capability and performance.
2) Development of equations for performance calculations.
3) Instrumentation
4) Computer program development.

The field engineering includes:

1) Proving of input devices.
2) Acquisition of plant operating data.
3) Interpretation of plant operating data and modification of computer program.
4) Determination of "Bogies."

In this paper the calculation for *turbine-generator cycle gross heat rate* will be used as an example in discussing the above.

Digital Computer

The computer installed at H. B. Robinson is fully solid-state with 4096 words of core memory. Fig. 1 illustrates the MARC block diagram.

A Scan and Alarm

The computer can scan up to 396 variables. Scanning is at a nominal rate of five variables per second. If alarm detection check shows an input to be off-normal, the alarm printer prints out (1) point identification, (2) value of off-normal point and (3) time of alarm, as well as indicate equipment in trouble on a conventional annunciator.

B Log

The computer can log up to 100 variables on two typewriters. Normal automatic log frequency is once per hour. As desired, more frequent logging can be manually initiated. Selected logged variables are averaged or integrated for a summary log which is automatically initiated every 24 hours.

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† Plant Superintendent, H. B. Robinson Plant.
†† Mechanical Engineer.

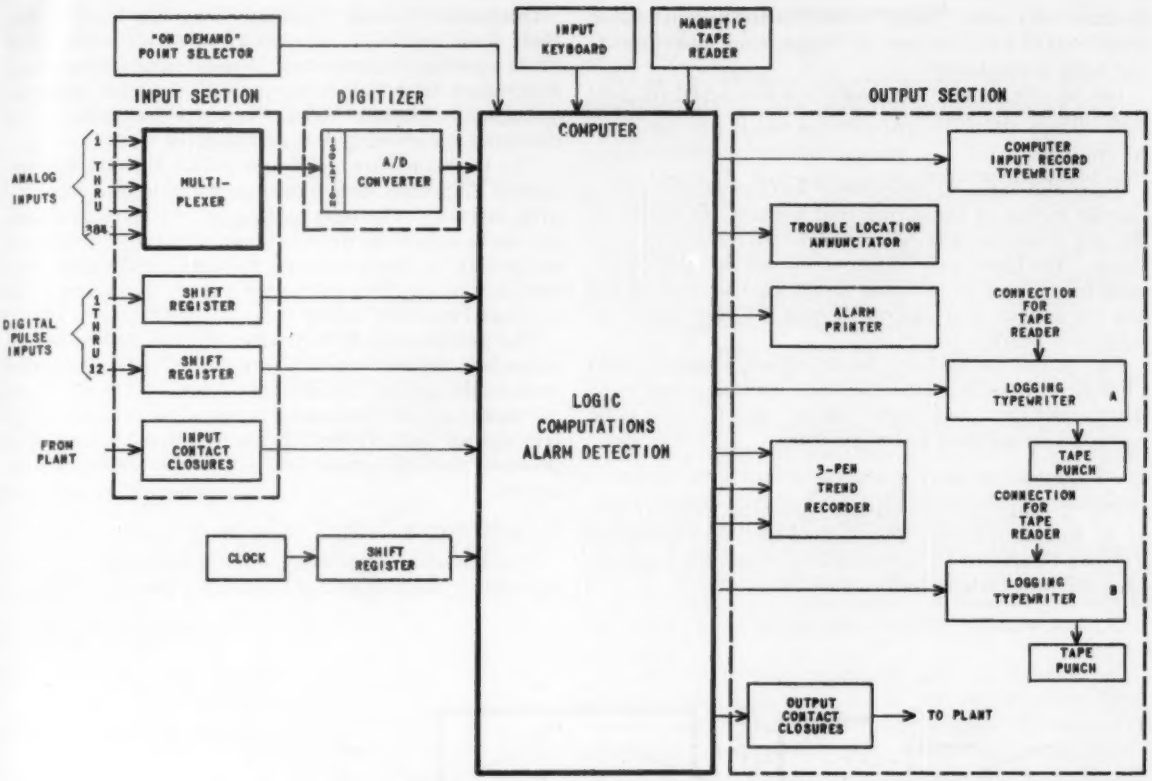


Fig. 1—Block diagram of the MARC system

C ON DEMAND REQUEST

The computer provides, by means of the "On Demand Point Selector," printing on an alarm printer of (1) value of one to three independently selected variables, (2) values of all variables or (3) all alarm set points. The operator can therefore follow digital trends of up to three variables. A "fast-normal" switch permits printing information at either 2-second intervals or approximately 2-minute intervals.

D TREND RECORD

The computer produces varying current signals for presenting to plant operators analog trend information of any three independently selected variables on a miniature trend recorder mounted on the operator's Boiler-Turbine-Generator Control Board. A "fast-normal" switch permits printing information at either 20-second intervals or approximately 2-minute intervals.

E CONTACT CLOSURES

The computer makes decisions as to closure of output contact(s) to external circuit(s) in accordance with stored program. The computer makes modifications to stored program by means of contact closure input(s).

F COMPUTE

The computer calculates performance of all major equipment as well as performance of the overall unit and compares these to stored optimum or "bogie" values. These computations will be discussed later.

G PERFORMANCE GUARANTEES

The MARC is guaranteed to meet the following:

1) Digitizing reproducible to within ±0.1 per cent of a known analog input.
2) Computations accurate to within ±1 (one digit).
3) Thermocouple linearizations accurate to within ±2 deg F of the measured millivolt input.

Performance Calculations

One very important function of the MARC system is computation of the performance of major plant equipment. These calculations would provide (1) operational information and (2) maintenance data.

For purposes of performance calculations, the plant was divided in three parts; (1) boiler, (2) turbine-generator cycle and (3) condenser. The turbine cycle was subdivided into: (1) feedwater heaters, (2) high-pressure turbine section and (3) intermediate-pressure turbine section.

In order to calculate these performances, it was necessary to develop suitable equations. An important consideration in developing these equations was the ability to detect, on a continuous basis, change in actual performance with reference to an optimum or "bogie" value. This requires that computation of actual performance be highly repeatable. The world *repeatable* should be stressed since it was a paramount consideration in all design and subsequent field work.

In order to obtain meaningful and useful results, it was

necessary to correct "bogie" values for the uncontrollable conditions of load, ambient air temperature and circulating water temperature.

Let us now look at the equations developed for performance calculations.

A Boiler

Since coal varies in composition and since there was no reliable means of measuring coal burned, the boiler efficiency equation was based on determination of heat losses. The losses were to be determined by utilizing the carbon-hydrogen ratio as calculated from analysis of flue gas for oxygen and carbon dioxide. These losses are tabulated below.

An optimum of "bogie" boiler efficiency which would provide an index of "best possible" operation was to be determined from field tests. Boiler efficiency was to be corrected for ambient air temperature.

B Turbine-Generator Cycle

Fig. 2 illustrates the turbine-generator cycle of the H. B. Robinson plant. The method used for calculating Turbine-Generator Cycle Gross Heat Rate was based on the simplified turbine performance test.

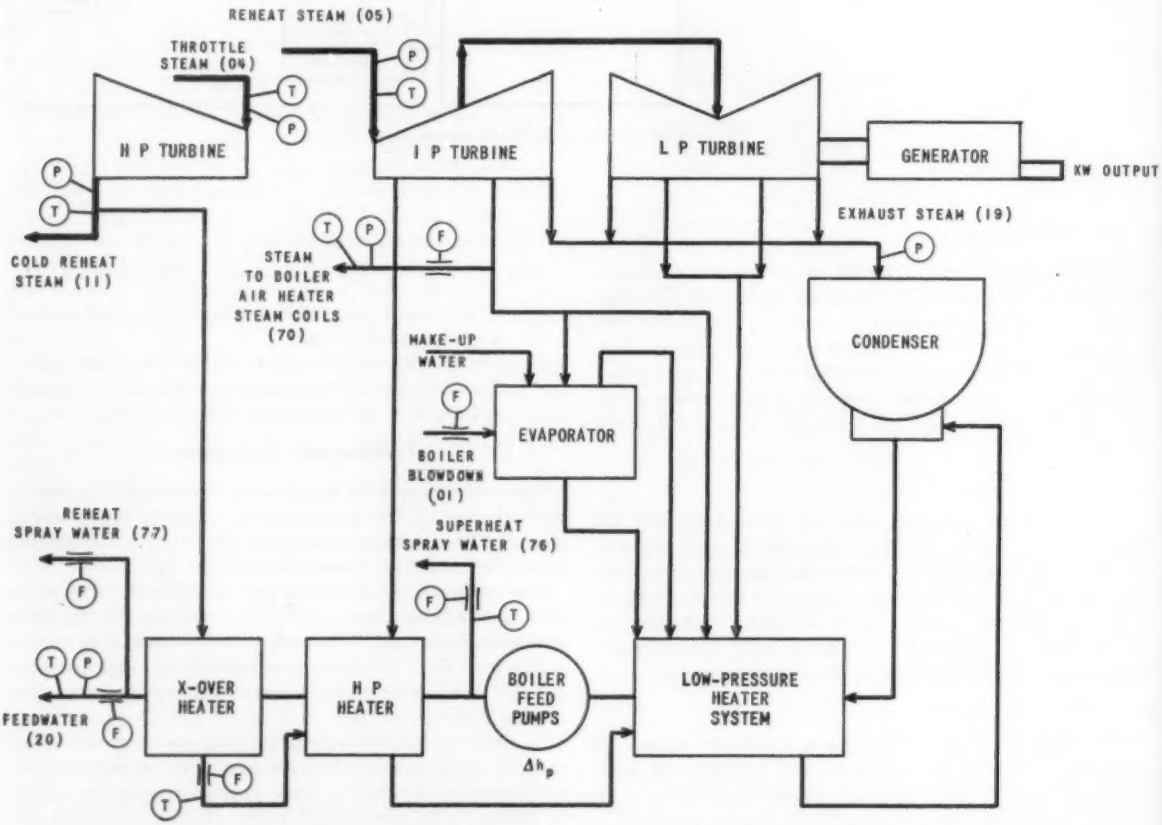
Optimum or "bogie" Turbine-Generator Cycle Gross Heat Rate was to be calculated to provide an index of "best possible" operation. "Bogie" values were to be determined from field tests conducted under optimum operating conditions. The "bogie" values were to be corrected for existing exhaust pressure.

The High-Pressure and Intermediate-Pressure turbine section efficiencies were to be calculated by the enthalpy drop method. The inlet and outlet pressures and temperatures were to be measured and efficiency determined as the ratio of the actual enthalpy drop to the isentropic enthalpy drop. The calculated values then were to be compared to design values.

The performance of Feedwater Heaters was to be calculated as the Fahrenheit Terminal Difference deviation from manufacturer's guarantee. Actual FTD was to be calculated as the difference between heater saturation temperature (determined from measured heater shell pressure) and the temperature of feedwater leaving the heater.

C Condenser

From existing circulating water temperature, condenser loading and number of circulating pumps operating,



Instrumentation
T = Temperature
P = Pressure
F = Flow

Net Heat Input, $Q = F_{04}(H_{04}) + F_{05}(H_{05} - H_{11}) + F_{01}(h_{01}) + (F_{20} + F_{76})\Delta h_p - F_{20}(h_{20}) - F_{76}(h_{76}) - F_{70}(H_{70} - H_{19})$

Turbine-Generator Cycle Gross Heat Rate $= \dfrac{Q}{\text{KW Output}}$

Fig. 2—Simplified turbine-generator cycle

expected exhaust pressure was to be determined from the condenser manufacturer's performance curves. The existing measured exhaust pressure was then to be compared to the expected value. Condenser performance was to be calculated as the change in heat rate (Btu/kwh) resulting from the exhaust pressure deviation from the expected value.

Boiler Losses

Loss in Dry Flue Gas:

$$LDFG = \left[\frac{128(CO_2) + 32\,(O_2) + 22{,}400}{52 - 1.1\,(CO_2) - 2.49\,(O_2)}\right]$$
$$\left[\frac{O_2}{100} \times 0.217 + \frac{CO_2}{100} \times 0.215 + \frac{100 - CO_2 - O_2}{100} \times 0.247\right]\left[T_G K - T_A\right]\left[10^{-4}\right] \quad (1)$$

Loss Due to Hydrogen in Fuel:

$$L_H = \left[9\left(\frac{845 - 40.45\,(O_2 + CO_2)}{52 - 2.49(O_2) - 1.1(CO_2)} + 0.045\right)\right]$$
$$[10.89 + 0.46(T_G K_1 - T_A)][10^{-4}] \quad (2)$$

Loss Due to Radiation:

$$L_R = -\frac{0.21}{0.6 \times 10^6} \times F_{02} + 0.6 \quad (3)$$

Loss Due to Moisture in Fuel: (4)

$$L_{MF} = \frac{K_2}{100} \times 7.2[1089 + 0.46(T_G K_1 - T_A)][10^{-4}]$$

Loss Due to Moisture in Air:

$$L_{MA} = 0.1 \quad (5)$$

Loss Due to Combustibles in Fly Ash:

$$L_F = K_3 \quad (6)$$

Unaccountable Losses:

$$L_U = K_4 \quad (7)$$

Boiler Efficiency Equation:

$$\Omega_B = 100 - L_{DFG} - L_H - L_R - L_{MF} - L_{MA} - L_F - L_U$$

Legend

O_2—per cent oxygen in flue gas
CO_2—per cent carbon dioxide in flue gas
T_G—Exit gas temperature
T_A—Ambient air temperature
F_{02}—Steam flow
K_1—Correction to Exit Temperature for air heater leakage, per cent
K_2—Moisture in coal, per cent

D Overall Unit

Unit net heat rate was to be determined from calculated *boiler efficiency and turbine-generator cycle gross heat rate* similarly, optimum *unit net heat rate* is determined from calculated "bogie" values.

In order to provide plant operators with an indication of auxiliary power usage, "optimum auxiliary power required" was to be calculated for existing plant conditions.

Instrumentation

We are all aware of the emphasis computers place on instrumentation. The computer may be making all the headlines, but input instrumentation is an equally important part of computer systems.

For the H. B. Robinson plant, instruments could not be randomly selected from manufacturers' catalogs. A more detailed analysis of instrument requirements was mandatory. Instrument manufacturers were not only pushed toward further improvements in accuracy and repeatability, but also toward improved reliability.

Two words can be used to summarize the criteria for selection of input devices and overall design of instrumentation for the H. B. Robinson Plant—*repeatability* and *reliability*.

The instrumentation philosophy can best be illustrated by looking at instrumentation selected for the *turbine cycle heat rate* calculation.

Let us again refer to Fig. 2. The input instrumentation necessary to perform this calculation is shown.

The accuracy and repeatability of heat rate calculations depend almost entirely on accurate and repeatable measurements. With this in mind, a concentrated effort was made in specifying and selecting suitable input instruments.

Feedwater flow measurement was of extreme importance since both main steam and reheat steam flow were derived from this basic measurement. By metering blowdown and superheat spray water, main steam could be determined. In turn, reheat steam flow could be determined from calculated main steam flow, metered crossover heater drain and reheat spray water flow, and accounting for turbine gland leakages.

The importance of feedwater flow measurement was obvious. Therefore, to meter feedwater flow a special orifice fitting, which permits removal of the orifice plate for inspection, was used along with an 800-in. mercury column type electronic transmitter. The flow element installed in the pipe section was calibrated at Ohio State University. This calibration and corrections for temperature were programmed in the computer.

In all cases the computer uses flow element differential readings rather than flow. This results in improved accuracy especially for low flow conditions. Also, in all cases where required, temperature and pressure corrections were programmed in the computer.

For temperature measurements, specially calibrated chromel-constantan continuous thermocouples were used. The calibration curve was stored in the computer.

For pressure measurements, solid-state electronic transmitters with a guaranteed accuracy of ±0.5 per cent of range and a guaranteed repeatability of ±0.1 per cent of range were selected. Where required, calibration data were stored in computer memory.

For measurement of the critical variable of generator output, a "Hall" watt transducer was selected. This transducer was tested prior to installation and showed an accuracy of better than ±0.5 per cent of range and a repeatability of better than ±0.1 per cent of range.

This now completed the design and system engineering. A digital computer had been purchased and installed with the capability and reliability thought necessary for the job. All inputs had been decided upon and after careful consideration instruments specified, pur-

chased and installed. Performance equations had been developed and, finally, all necessary information required for initial programming had been submitted to the digital computer manufacturer.

We were then ready to proceed with the field engineering.

Proving of Input Devices

The first phase of field engineering was to prove each input device. This was accomplished in three basic steps:

1) The wiring from input devices to computer input terminals was checked.
2) Each transducer was calibrated. Since the computer was the most accurate measuring device in the plant (guaranteed accuracy of 0.1 per cent) it was used for calibration.
3) Each input signal was checked for magnetic pickup and ground loops.

This first phase, although time consuming and tedious, had to be completed before any further field work could be done.

Data Acquisition

The second phase of field work was data acquisition. When one considers that most plant tests are conducted with generator load pegged and with all plant variables completely stabilized, the extent of the job necessary to continuously perform calculations under varying plant conditions becomes obvious.

Typical plant recorder charts illustrate the inherent cyclic characteristics of steam power plant. They also illustrate the interaction that exists between plant variables. These effects must be greatly minimized in order to arrive at performance results meaningful and useful to plant operators and supervisory personnel.

The computer program was prepared so variables that enter performance calculation are "read" by the computer every 20 seconds. Readings are averaged at the end of the calculation cycle (approximately 120 seconds) and calculations are performed with these readings. The 2-minute performance calculations in turn are averaged (load-weighted) over an hour and day. These 2-minute calculations are available for presentation on the trend recorder and/or alarm printer.

Is this averaging sufficient to take care of the cyclic and interaction effects previously mentioned?

How about the performance equations developed? Are these equations valid under all operating conditions?

What is the optimum performance of the plant and the major equipment?

These questions can only be answered by accumulating sufficient plant operating data under steady load and normal load-control conditions.

Data was accumulated over a period of months using the spare typewriter. Thirty-three plant variables used in performance calculations were averaged and logged in 3-minute intervals under steady load and normal load-control conditions.

Interpretation of Plant Data and Modification of Computer Program in Accordance with This Data

Now that this mass of plant information has been accumulated, what is done with it? This leads to phase three; the interpretation of plant data and modification of the computer program in accordance with this data.

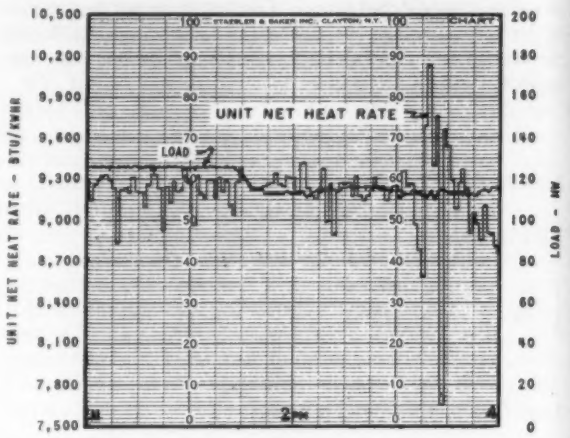


Fig. 3—First recording of calculated unit net heat rate, Dec. 9, 1960

Some indication of the job to be done can best be illustrated by looking at Fig. 3. This shows the first recording of calculated *unit net heat rate*. It is obvious that this kind of information is useless.

The accumulated data must now be studied so that the computer program and performance calculations can be modified to make available meaningful information to plant operators and supervisory personnel.

It was just stated that all variables used in performance calculations were "read" every 20 seconds and averaged at the end of the scan cycle. The first step was to verify that this frequency of averaging did not introduce errors in performance calculations.

The 20-second averaging period was found suitable for all variables, except feedwater flow. In fact as it turned out, feedwater flow cycled at a period of very close to 20 seconds. Therefore, a 5-second period was chosen for feedwater flow averaging. Its effect can best be illustrated by Fig. 4.

Satisfied that the frequency of averaging was suitable for all variables, the next problem was to minimize the effect of overall plant cycling on performance calculations. Since computer memory was at a premium, an attempt at elaborate mathematical solutions was out of the question. A convenient artificial solution had to be found. One possible solution was to introduce damping or smoothing. However, care must be taken in introduc-

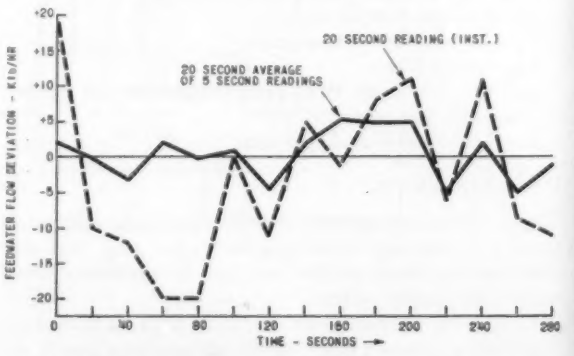


Fig. 4—Feedwater flow at constant load as determined by computer

ing damping since excessive damping produces a time lag in providing useful information.

For the calculation of *turbine gross heat rate*, by trial and error, a smoothing factor was decided upon. Fig. 5 illustrates the effect of this smoothing factor. This smoothing factor is such that the present calculation is worth one-half, the previous one-fourth, the one before that one-eighth, and so forth.

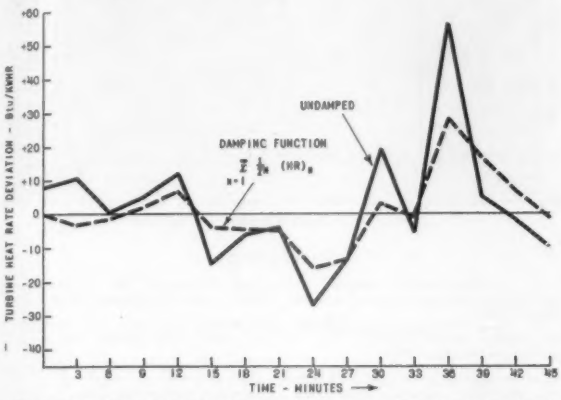


Fig. 5—Calculated turbine cycle gross heat rate, cycling at constant load

This smoothing function reduces the cycling of *calculated turbine-generator cycle gross heat rate* at constant load to ±15 Btu/kwh.

Numerous tests showed that this smoothing factor was also satisfactory for varying loads as well as constant load.

The next step was to determine interaction effects resulting from temporary disturbances. Once again let us use *turbine cycle gross heat rate* as an example.

Previously it was stated that feedwater flow was used as the basic flow measurement. Both main steam and reheat steam flow are determined from this basic measurement. Although this technique results in better metering, it does present a complication.

The boiler can be thought of as a huge storage device. The equation for calculating *turbine-generator cycle gross heat rate* does not account for changes in boiler storage. Feedwater flow is controlled by boiler drum level as well as steam flow-feedwater flow comparison. As long as drum level remains relatively constant, calculated values for main steam and reheat steam flow are valid. However, for transient changes in drum level, the main steam and reheat steam flow calculations are not valid until drum level has again stabilized.

Almost any disturbance such as putting major equipment in or out of service, changing control set points, coal stoppages, etc., results in drum level disturbances. These drum level disturbances result in some meaningless values for calculated turbine-generator cycle heat rate Fig. 6 illustrates the effect on drum level and calculated *turbine heat rate* resulting from taking a boiler feed pump and condensate pump out of service.

By varying the smoothing functions in relation to drum level disturbance, the effect on calculated *turbine heat rate* is greatly reduced. The same technique proved satisfactory for almost all transient disturbances.

Determination of Bogies

It was now possible to proceed with the determination "bogie" values. It was necessary to run a series of tests conducted under "best possible" operation. From this series of plant tests, a bogie curve was determined. This permitted the presentation of information to plant opera-

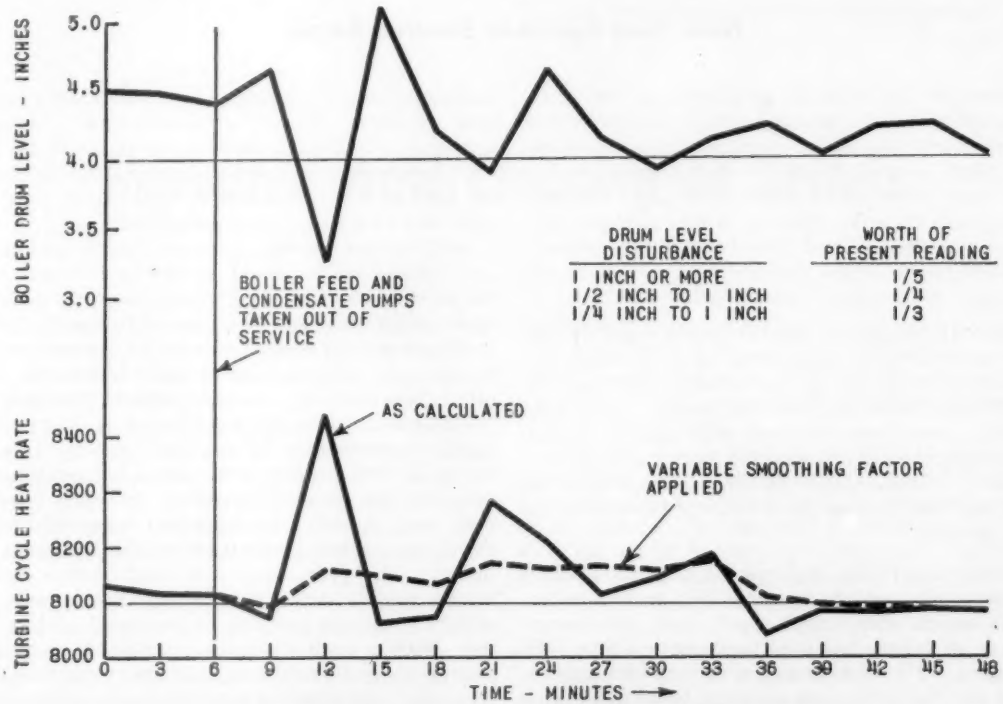

BOILER DRUM LEVEL - INCHES
DRUM LEVEL DISTURBANCE
WORTH OF PRESENT READING
1 INCH OR MORE 1/5
1/2 INCH TO 1 INCH 1/4
1/4 INCH TO 1 INCH 1/3
BOILER FEED AND CONDENSATE PUMPS TAKEN OUT OF SERVICE
AS CALCULATED
VARIABLE SMOOTHING FACTOR APPLIED
TURBINE CYCLE HEAT RATE
TIME - MINUTES

Fig. 6—Effect of drum level variations on calculated turbine cycle heat rate

tors and supervisory personnel which would aid in operating the unit at maximum efficiency.

Fig. 7 shows a recent recording of calculated *turbine generator cycle gross heat rate* as well as the deviations from "bogie." A comparison wide Fig. 3 indicates the progress made.

Conclusion

Putting a computer system to work is indeed a great challenge. We are faced with new types of problems and must use new techniques to solve these problems.

Considerable progress has been made to date, but some work must still be accomplished before entirely achieving the results envisioned by the original concept. With some further improvements in measuring techniques and continuation of the study of plant dynamics, we feel confident that the elusive last inch of step three will be successfully taken at H. B. Robinson and the full potential of the MARC system will be realized.

The rewards from the complete realization of the MARC system potentials are certainly enticing, and with a little extra effort they are well within reach.

Acknowledgments

The authors wish to acknowledge the assistance and cooperation of personnel at the H. B. Robinson plant.

Messrs. W. A. Summers, Consulting Engineer, and J. V. Sweeney, Mechanical Engineer of Ebasco Services, Inc., and C. R. Wallace, Operating and Results Supervisor, and J. Bullock, Electrical Engineer, of Carolina Power & Light Co. have been an important part of this project.

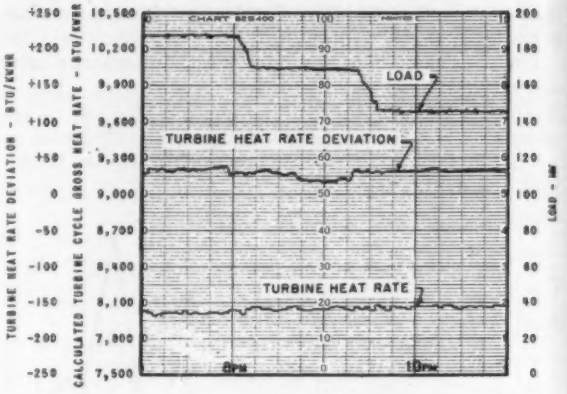


Fig. 7—Recording of calculated turbine-generator cycle gross heat rate April 10, 1961

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2. "Code Testing of Large Boilers—Input-Output or Heat-Loss Method," J. A. Bostie and W. F. Long; Paper No. 60PWR-5, ASME-AIEE Power Conference, September 1960.
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4. "Effect of Exhaust Pressure on the Economy of Condensing Turbines," A. Keller and J. E. Downs; Paper No. 53-SA-73 ASME Semi-Annual Meeting of Power and Hydraulic Division, June 1953.
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New Heat Source in Boosted Burner

An American Gas Assn. group meeting at the A. D. Little Laboratories in Cambridge, Mass., recently heard reports on their Association-sponsored basic investigation program of the thermodynamic properties of a boosted burner when fueled with natural gas. The program is part of the AGA effort to explore new gas uses. One demonstration showed that boosting the natural gas-air flame produces heat that melts a variety of metals from copper to tantalum (melting point, 5400 F).

Further the addition of electric power equal to one-half the chemical combustion power at an optimum air-fuel ratio boosted the gas specific enthalpy (heat content) from 1100 Btu/pound to 1600 Btu/pound. Enthalpies of 1900 Btu/pound were obtained with fuel-rich flames, and still higher figures are expected from increased electrical power. Tests indicate also that the heat flux to an external heat sink increases by a factor of three when the flame is boosted.

The high temperature, high specific enthalpy product of the electrically boosted burner is held to be a potential heat source when either rapid, high temperature heating or an intense localized heat source above 3000 F is desired. The demonstration showed the applicability of the burner to impingement heating for such processes as cutting, welding, spalling, sacarfing, and drilling because of the flame's high temperature and high heat capacity. Heating of materials to a very high temperature by feeding directly into the flame is a logical use for the new device, especially when organic materials are used since slower methods would destroy the molecules and form carbon and various oxides.

Both radiant heating, as in open hearth steel furnaces, and indirect heating could use the new boosted burner, the meeting was told, if refractory materials for suitably high temperatures can be economically used. Fluidized bed processes, for which a number of new uses are opening up, and submerged combustion techniques are two other applications the researchers found promising.

The meeting learned that the use of cheap chemical energy supplemented by relatively expensive electrical energy to obtain higher than normal temperatures is the basis for the burner's operating economy. Operating costs were described as dependent upon the fuels, oxidants, and electric power used and the temperatures required. The group was told that design flexibility makes possible utilization of any commercially available fuel—natural gas, fuel oil, powdered coal or hydrogen—with a range of oxidizers from air or oxygen to fluorine or exotic mixtures. By varing the fuel-oxidizer feed rates, the burner is expected to provide a reducing, neutral, or oxidizing atmosphere.

Fig. 1—Stressed boiler tube end—twelve acid cleanings

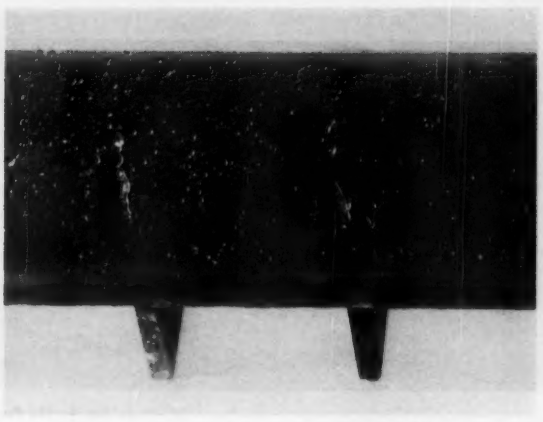

Fig. 2—Boiler tube with field welded lugs—six acid cleanings

By J. K. RICE

Cyrus Wm. Rice & Co.

Every one knows that repeated acid cleaning is supposed to be a safe procedure—but many who have used frequent acid cleaning as a substitute for water conditioning have experienced failures. The author's experiments present convincing evidence that the type of deposit and reaction of deposit with the acid inhibitor may go far toward explaining "acid cleaning corrosion" failures.

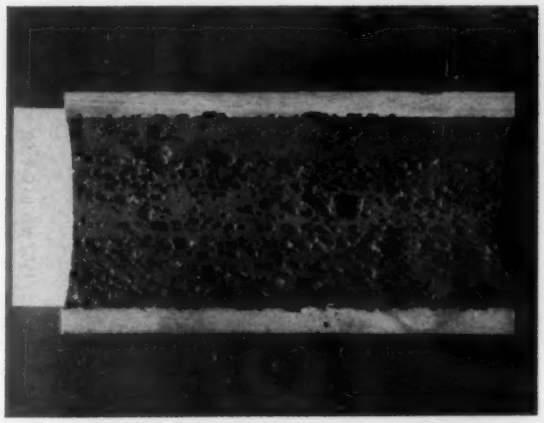

Fig. 3—Boiler tube—twenty-seven acid cleanings

Repeated Acid Cleaning of Boilers

MANY years ago when acid cleaning of boilers was an infant art, quite a few remember the considerable concern on the part of the uninitiated that boilers would be damaged by corrosion if acid cleaning was employed. The effectiveness of acid inhibitors in reducing corrosion was demonstrated in the laboratory with repeated prolonged cleaning of test pieces of appropriate materials; in the field, by successful cleanings that left the boiler metal visibly unattacked. The fear of corrosive attack disappeared under the weight of evidence.

Since those infant days, cleaning with inhibited hydrochloric acid has become an accepted procedure. Such cleaning has allowed us to prevent future problems by preparing a clean, uniform surface in the boiler. It has also allowed an economical correction of inadequate water treatment, boiler design, and boiler operation. As a result many have succumbed in certain instances to the proposition that it was cheaper to acid clean each year than to install equipment to prevent deposits from forming. On the evidence available this latter argument was often very compelling.

From the outset most of us have recognized that certain conditions could arise where acid cleaning could cause corrosion failures. For some recognition came as a rude shock. The structure of weldments in contact with the water became very important; surface imperfections introduced in fabrication, heavy local stressing or cold working, all became focal points for localized corrosive attack that could and did penetrate the boiler tube walls with repeated cleaning. Fig. 1 shows cracks in a rolled tube after 12 acid cleanings. Fig. 2 is a tube section with field-welded external hangers. In this example, the extreme penetration occurred in a narrow

Fig. 4—No deposit—inhibited acid

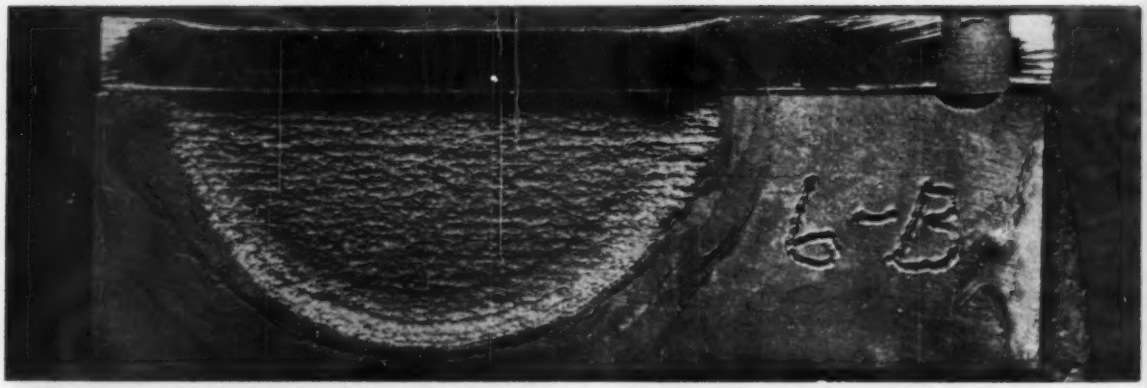

Fig. 5—No deposit—uninhibited acid

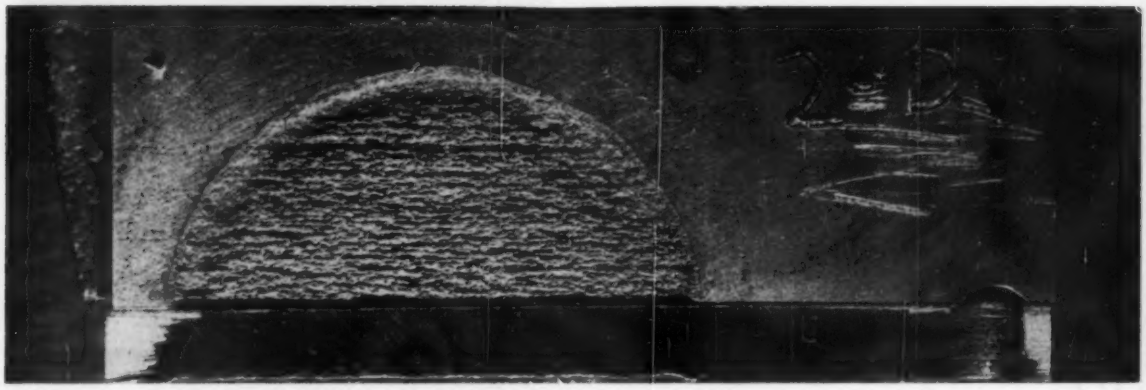

Fig. 6—Boiler deposit—high dispersant content inhibited acid

band of martensite structure that resulted from rapid chilling of the weld; the scattered pitting was given little serious consideration since it was greatly overshadowed by the immensely greater weld attack. Others can recall many similar instances of extra sensitivity to acid attack. In most of the author's experience, the "sensitivity" was eliminated and the corrosion was quite correctly not judged the fault of acid cleaning.

As time passed and boilers were repeatedly cleaned, a few began to see disturbing evidence that the cost of acid might be the lesser fraction in a total cost that included metal replacement. Anyone who has seen a boiler after ten strong acid cleanings has seen the sharp roughening of tube ends, the deep etching of tube draw marks, the loss of bolt threads and many other similar effects. These effects were often attributed to excessive acid temperature in an early cleaning or to too much ferric iron in the spent solvent. As more boilers have been cleaned more often, more such effects have been noted to the point that it is difficult to assign them to such specific lapses in cleaning technique. In recent years, the author has encountered instances of extreme corrosion of tubes and tube ends after twenty to twenty-five acid cleanings. It is also true there are units that have been acid cleaned 20–25 times no more carefully and show a far less degree of attack. However, that the extreme attack shown in

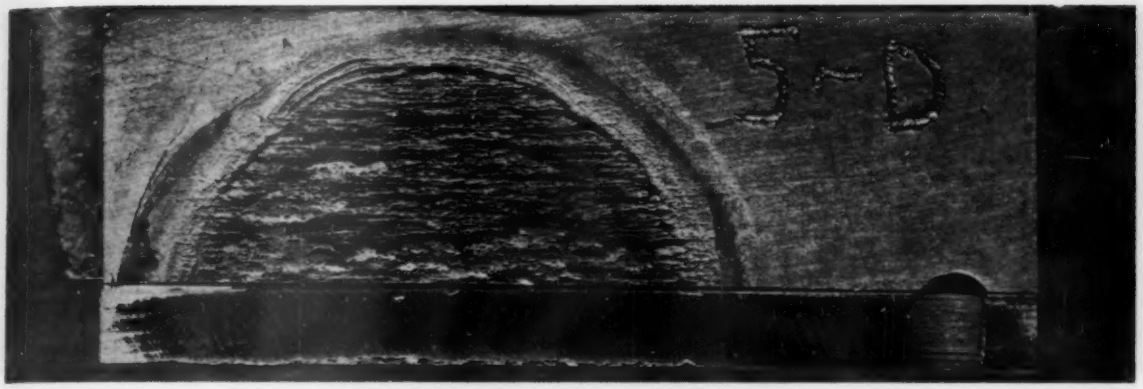

Fig. 7—Lignin sulfonate dispersant deposit—inhibited acid

Fig. 8—High calcium phosphate L.P. boiler deposit—inhibited acid

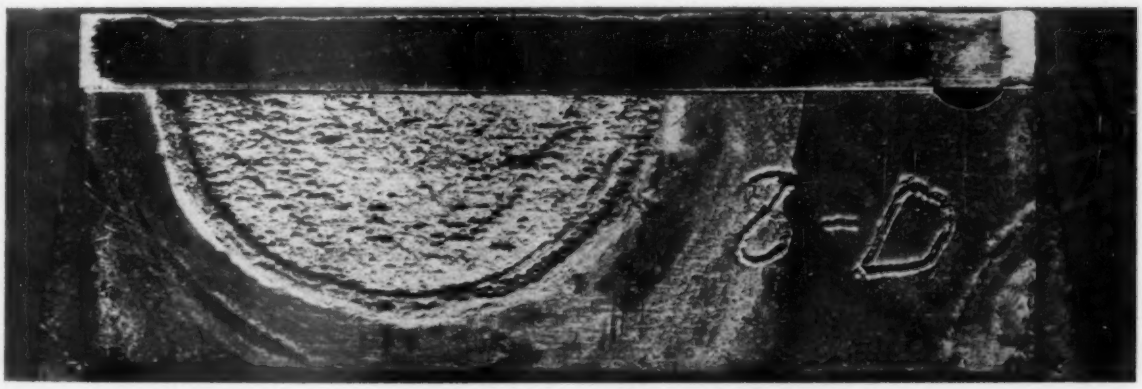

Fig. 9—40 per cent Cu, 60 per cent Fe_2O_4, H.P. boiler deposit—inhibited acid

Fig. 3 does not always occur after 25 cleanings is of little consolation to the operator who faces the expense of retubing his boiler.

In order to learn if different deposits of the types encountered in boilers might affect the amount of acid attack experienced, the author performed an experiment in which a number of 1- × $1^1/_2$-in. test specimens were predeposited with different boiler deposits and acid cleaned. After each cleaning the test specimens were rinsed, soaked with 2 per cent soda ash solution for 30 min, rinsed and then test specimens were redeposited and the cleaning repeated. This cycle was repeated seven times. Each cleaning was at 150 F for six hours with inhibited 5 per cent hydrochloric acid solution. The amount of deposit each time corresponded to approximately $^1/_{16}$ in.; the volume of solvent per square inch, to that in a $2^1/_2$ in. I.D. tube. The deposit and the solvent were contained on the flat surface of the specimen by a polyethylene tube heat-sealed to the surface.

Let us state emphatically that this experiment was designed only to determine if different deposits gave rise to different corrosion rates. There was no attempt to determine the corrosion rates that might be experienced in an actual boiler.

Fig. 4 to 13 shows the specimens at approximately 3X after each was cut in two, and one-half mounted edgewise

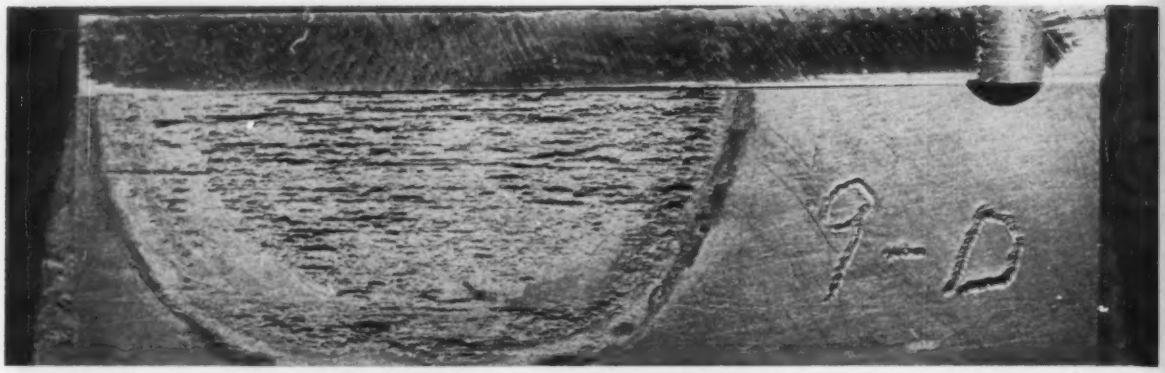

Fig. 10—High Fe_2O_3, L.P. boiler deposit—inhibited acid

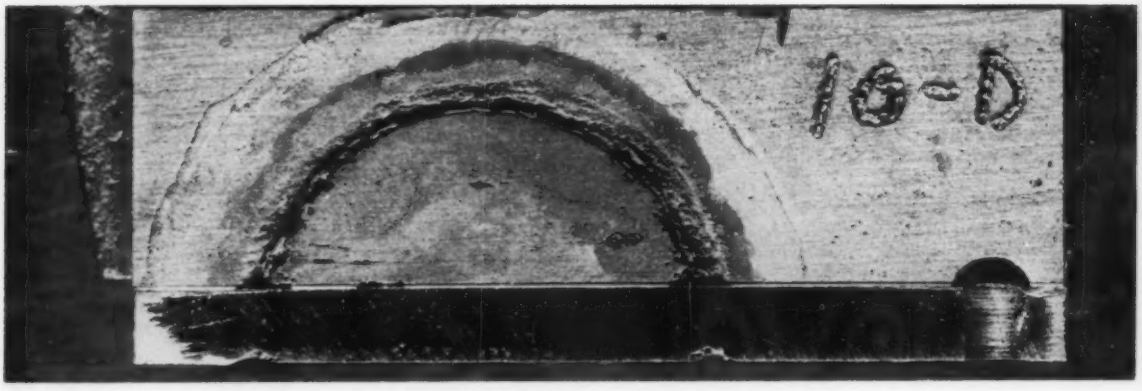

Fig. 11—Analytical grade Fe_3O_4 deposit—inhibited acid

Fig. 12—Analytical grade 90 per cent Fe_3O_4-10 per cent Cu deposit—inhibited acid

to show the extent of penetration. It is obvious from an examination of the specimens that the amount of attack with repeated acid cleaning is greatly influenced by the type of deposit in contact with the surface at the start of each cleaning.

While the results of the investigation presented here are not intended to explain why each deposit acted as it did, it does appear that certain types of organic dispersants if present in deposits may act by absorbing or reacting with the inhibitor. It also appears that the physical state of the individual components, whether amorphous or well crystallized, affects the results as evidenced by comparing Fig. 11 (a 40 per cent Cu–60 per cent Fe_3O_4 high pressure boiler deposit) with Figs. 12 and 13 (mixture of analytical grade Cu electrolytic dust and Fe_3O_4).

This laboratory evidence leads, in the author's opinion, to an explanation of the field experience of differing degrees of attack with the same number of cleanings. The evidence points strongly to deposits as a major factor in determining the extent of corrosion with each cleaning. Unless this deposit effect is taken into account, the author does not believe that it is safe to predict twice yearly or even yearly acid cleanings as being safe with a

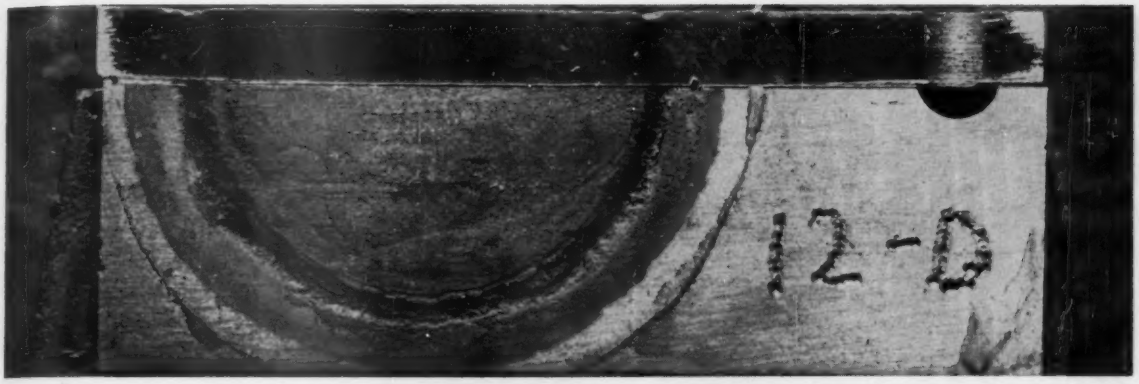

Fig. 13—Analytical grade 10 per cent Fe_2O_4-90 per cent Cu deposit—inhibited acid

cost of only the amount for the acid and the cleaning service. It seems that in the absence of precise data a more realistic estimate of the total cost of each strong acid cleaning should include approximately $^1/_{20}$ of the cost of retubing the boiler.

Perhaps if such a total cost is used, many of the external treatment processes that will eliminate the need for or reduce the requirement of cleaning may be economically attractive. In any event the evidence shows need for more study of the effect of repeated acid cleaning.

Progress of Flyash Utilization

The fly ash situation is quite similar in many respects to the early circumstances which surrounded the slag disposal problem some 50 years ago. H. H. Russell, BCR, advised the National District Heating Assn. recently. Gradually the handling companies processed, graded and upgraded the crude slag to make it acceptable for the market outlets. Today slag is an established building material in a variety of building uses but the bulk represents aggregate of different grades, most of which goes into paving construction. Today there are slag associations which serve the whole producer industry and are recognized in the building fields. The Standard Slag Association has its own laboratory and its purpose is to establish markets through research and development work.

In the case of fly ash it too has found important uses in the paving and construction fields. These markets statistically could absorb all the fly ash produced but here is a very misleading analysis to make, Mr. Russell emphasized, because there are many facts which in reality prove that this could not be realized until these many problems concerning quality and economics are answered satisfactorily.

Any market use he went on to say requires that several fundamental questions be answered if regular use is to result. These are:

1. Will fly ash give quality equal to or better than the material now used?
2. Does fly ash quality meet the standards required by the customer and can the quality be maintained?
3. Does the use of fly ash save money for the customer?
4. Does the customer have proper handling equipment for fly ash or is he willing to make the required investment?

After all these have been answered satisfactorily it must then be firmly established that supplying costs for the utility are lower than disposal costs.

If affirmative answers for all these questions can be guaranteed on a continuous basis, it is possible fly ash can find an outlet. These requirements are no different than those which a manufactured product is required to meet and in some cases they are tighter. In the case of a manufactured product standards and performance are routinely built into the design and processing. In the case of fly ash we are talking about a by-product which is strictly a cost nuisance to the utility plant and is treated accordingly. Very little can be done in the way of process control to give a continuous uniform quality. To the coal producers this by-product problem is even more removed from his day to day operations.

The fly ash situation Mr. Russell felt was not much different than was that encountered by the slag people 50 years ago when they first started to look for commercial outlets. A high percentage of the fly ash sold today is that material which by some selection can satisfy the established markets. Some outlets use fly ash as it comes directly from the source requiring no quality or other specification. This leaves the greatest part of the fly ash tonnage without any profitable outlet available to it and this is the problem.

The BCR has been active in the field of fly ash utilization and has tried to develop outlets. Much information has been assembled on the status of the problem, surveys been conducted and efforts made to get fly ash considered in the established markets.

A survey made about five years ago showed that in 14 Appalachian states there was a market potential three times the supply of fly ash in these states when we considered only concrete and asphalt road building. A later survey of the whole country showed that 14 states permit fly ash use in road building—11 of these permit its use in bituminous mixes. In the case of concrete paving seven states permit fly ash in concrete paving by special or written permission. This means that some special group interested in fly ash must open this market.

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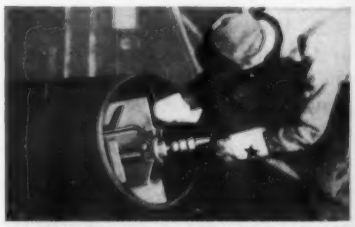

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Abstracts from the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion, Ltd., London, W. C. 1)

Fuels: Sources, Properties and Preparation

The Physical and Chemical Properties of the Structural Components of Bituminous Coal. XI. X-ray Diffraction of Macerals and Maceral Cokes. C. Kröger and G. Mues. *BrennstChemie* 1961, **42** (Feb.) 33–40 (*In German*).

The evaluation of the diffraction curves has given new insight into the size of aromatic lamellae, the percentage distribution and proportion of amorphous macerals. The examination of the cokes has shown the relation between temperature of coking and size and growth of the lamellae.

Basic Nitrogen in Coals. J. D. Brooks and J. W. Smith. *C.S.I.R.O. Reprint* 1960, 5 pp.

A major proportion of the nitrogen in a wide range of coals occurred in the form of basic primary, secondary and tertiary amine groups. These may occur in cyclic structures.

Mechanical Handling

Magnetic Protection Equipment for Coal-Handling System. H. W. Buus. *Pwr Engng* 1961, **65** (Feb.) 72–4.

Equipment for removing tramp iron from coal conveyor belts prior to crushers or pulverisers is described and the best way of installation discussed. Charts for the selection of rectangular suspended magnets and permanent magnetic pulleys are provided.

Steam Generation and Power Production

Wetness in Steam Cycles. B. Wood. *Proc. Inst. Mech. Engrs* 1960, **174** No. 14, 491–534.

A review of present knowledge of the properties of wet steam and the difficulties and damage caused by it in the water-steam cycle.

Some Contributions from Nuclear Power to Engineering Practice. I. Davidson. *J. Brit. Nucl. Energy Conf.* 1961, **6** (Jan.) 27–35.

Problems and design improvements of pressure-vessels made of steel and prestressed concrete are discussed. Recent designs are outlined.

Band Reinforced and Layer Built Pressure Vessels. P. J. Palmer. *Brit. Weld. J.* 1961, **8** (Feb.) 51–7.

In band reinforced vessels the bands are constructed from thin plates and carry only hoop load, in layer built vessels the bands are jointed by circumferential welds and carry longitudinal loads. The theories relating to these vessels and their merits are discussed. Design formulae are presented.

Lobed Pressure Vessels. J. P. Duncan and N. W. Murray. *Engineer* 1961, **211** (Feb. 3) 169–72.

A new form of pressure vessel is proposed consisting of a special frame, cage or three-dimensional structure from whose members spring three-dimensional membranes or domes. Experiments on models are described and the results of stress investigations presented.

Welded Boilers and Pressure Vessels. Anon. *Engineer* 1961, **211** (Jan. 27) 122–5.

Lengthy abstracts are given of two papers: 1. A Comparison of United States, Eureopean and British Commonwealth Codes for the Construction of Welded Boilers and Pressure Vessels by J. F. Lancaster; 2. Pressure Vessel Design Requirements in the Near Future by W. B. Carlson.

New Design of Tower Boilers. O. von Swietochowski. *Energie und Technik* 1961, **13** (Feb.) 59–61 (*In German*).

A single-pass tower design was chosen for a Benson boiler rated at 50 t/h at 127 atü and 500 C and pressurized cylindrical furance with a single burner in the centre of its floor because of the very restricted space available at a chemical factory. The steel chimney is placed on top of the boiler. The furance walls consist of helically wound evaporating tubes; at the top end of the furnace a square pass follows containing the final evaporator, superheater, economiser and tubular air preheater. The controls including starting are completely automatic. The heating surfaces are lined on the outside by a thin layer of chamotte and this surrounded by a leak-proof casing to avoid acid corrosion; escape of flue gases is prevented by air under pressure flowing between the inner and outer casing. A similar natural circulation boiler is under construction.

Design of Heat-Exchangers for Nuclear Plants. B. F. Ridal and J. H. Wilson. *Chem. Proc. Engng* 1961, **42** (Feb.) 55–8.

The difficulties involved in calculating the heat transfer surfaces required in steam raising plant for nuclear power stations by the exchange of heat by forced convection from hot gas to water and steam are discussed and some equations found useful in this respect are given.

Calculation of the Water Circulation in Natural Circulation Boilers. H. Sebulke. *Techn. Überw.* 1961, **2** (Feb.) 51–4 (*In German*).

A simplified method of calculating the circulation is presented in which a circulation diagram is used to determine the pressure difference at the inlet and outlet of the riser tubes as a function of the water velocity and heat uptake. From these values the water volume and conditions can be easily computed.

Preservice Cleaning of Power Plants. B. Tuck. *Brit. Pwr Engng* 1961, **2** (Feb.) 62–4.

The main reasons for preservice cleaning of boilers are the removal of welding slag, mill scale, silica, oil and grease and other foreign matter. The methods using 5 per cent hydrochloric acid suitably inhibited, sulphuric and/or citric acid and that developed by Siemens-Schuckertwerke in Germany are briefly outlined. Such cleaning has been carried out in the once-through boiler at Margam steel works and recently in a 120 Mw boiler at Rugeley station where the economizer, boiler, superheaters and reheaters, all feed water and steam lines, low and high pressure feed heaters, deaerator and tank and the condenser were included.

Refractory Performance in Oil-Fired Boilers. D. P. Peplow. *Brit. Pwr Engng* 1961, **2** (Feb.) 31–6.

Experience with various refractories in false bottoms and ignition belts of boilers at Marchwood and Poole stations has shown that those with high alumina content and high refractoriness have performed best, have a good spalling resistance and are least affected by oil ash. Hand ramming is preferred to gunning by giving a denser structure.

Flameless Combustion. Anon. *Chem. Proc.* 1961, **7** (Mar.) 18–9.

In this process for dealing with the waste liquor of pulp and paper mills a heated mixture of liquor and water is oxidized by compressed air at low temperatures (260–315 C) and pressures of 1400–1500 psi and the resulting steam and hot gases are passed to a turbine, whilst the liquid residue is fed to separators and heat exchangers to generate additional steam and hot water. The efficiency is stated to be up to 95 per cent.

Water-Side Corrosion and Water Treatment

The Development of Boiler Feed-Water Treatment—1. A. G. D. Emerson and F. R. Jarrett. *Steam Engineer* 1961, **30** (Feb.) 147–51.

An historical review outlining the reasons for water treatment and a description of the troubles experienced in the past, methods of treatment and testing and control.

Phosphate Water-Conditioning. Anon. *Pwr Wrks Engng* 1961, **56** (Feb.) 108–110.

A brief account of its advantages, methods of application, precautions, threshold treatment.

Corrosion Prevention by Water Treatment. Anon. *Fuel Efficiency* 1961, **9** (Feb.) 38.

Prevention of corrosion of evaporators, condensate lines and heat exchangers can be obtained by adding Hagafilm, an octade cyclamine to hot water at rates varying from 3.5 to 10 ppm. This agent has a dispersing action on iron oxide deposits and thus increases heat transfer; it also promotes dropwise condensation and keeps surfaces clean.

What Causes Corrosion in the Condenser Steam Space. R. A. Wilson. *Pwr Engng* 1961, **65** (Feb.) 57–9.

Ammonia is regarded as the main contributor to stress corrosion of Admiralty, aluminium, brass and copper alloys when oxygen, moisture and stress are present. Since these can never be entirely excluded the use of stainless tubes in condensers is advocated.

Gas-Side Corrosion and Deposits

Acid Deposition in Oil-Fired Boilers: Comparative Trials of Additives and Testing Techniques. P. A. Alexander, R. S. Fielder, P. J. Jackson, E. Raask and T. B. Williams. *J. Inst. Fuel* 1961, **34** (Feb.) 53–72.

The results of extensive tests with various additives at Bromborough and without additives at Ince power station are reported and discussed. It is concluded that: 1. Short-term methods of tests should include measurements of acid deposition rate and determination of sulfur oxides; 2. Excess air to be a minimum to suppress SO_3 formation; 3. Magnesium carbonate and zinc both to be considered in future trials and feeders made more reliable; 4. Injection of p.f. ash is effective only at SO_3 concentrations below 10 ppm; 5. Research into the relation of SO_3 formation and S content of the fuel to be instituted; 6. Research on the rôle of economizer and air heater deposits on the oxidation of SO_2 to be carried out.

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Reactions of Magnesium with Inorganic Constituents of Heavy Fuel Oil and Characteristics of Compounds Formed. W. D. Niles and H. R. Sanders. *A.S.M.E. Preprint* No. 60-WA-278 1960, (Dec.) 8 pp.

After checking the literature on the sodium-vanadium-sulfur system the magnesium-vanadium-sulfur system was investigated and the compounds formed analyzed. Predictions of the compounds likely to be formed under operating conditions were made and checked against actual deposits in boiler and gas turbines. The influence of the SO_3 partial pressure and temperature on the type of compound formed is stressed.

Control of Sulfur Corrosion in Boilers. H. N. Wigan. *Fuel Effic.* 1961, **9** (Jan.) 50–2, 54.

After discussing the causes and measures of prevention of high and low temperature corrosion and deposit formation in small and medium sized oil and coal fired boilers the mode of action of Desulforol in admixture to fuel oil (1:1000) is explained. It affects the internal cohesion of the oil and thus improves atomization and combustion, retards oxidation of SO_2 to SO_3, neutralizes sulfuric acid vapor, reduces deposit formation and makes any deposits easily removable, and also removes any scale already formed.

Mechanical Dust Collectors of Low and Medium Efficiency. R. Jackson. *B.C.U.R.A. Monthly Bull.* 1960, **24** (Aug./Sept.) 397–427.

The design, mode of action and efficiency of the following are reviewed: 1. Louvered dust arrestors; 2. Scroll type collectors; 3. Fan collectors; 4. Low loss swirl collectors.

Power Generation and Power Plant

The Electric Power Industry of China. Yu. M. Avsenel. *NLL Transl. Bull.* 1961, **3** (Mar.) 173–8.

Generation of electric power in China has increased by 963 per cent between 1949 and 1959 and some details are given of new installations, new transmission lines and future installations.

New South Wales Develops Coalfield Power Stations. Anon. *Elect. J.* 1961, **166** (Jan. 13) 110–1.

Brief details are given of future extensions to the Wangi, Tallawarra, Wallerawang and Vales Point steam power stations in New South Wales. The Wangi station has a present capacity of 270 Mw; this is to be increased to 330 Mw. The 120 Mw Tarrawarra station is to be increased to 320 Mw. The 120 Mw Wallerawang station is to be increased to 240 Mw by 1962. The first set of the Vales

Point station is to be commissioned in 1963 and the station will have an ultimate capacity of 1000 Mw. *From C.E.G.B. Digest* 1961, **13** (Feb. 18) 457.

Fuel and Energy Required for Steelmaking by the VLN Converter Process. G. G. Fletcher and R. A. Pullen. *J. Inst. Fuel* 1961, **34** (Feb.) 46–52.

A detailed analysis of the various fuels or power required in the VLN (very low nitrogen) steel process is presented.

The Breen Plant Story. P. Sporn and S. N. Fiala. *Elect. Wrld* 1961, **155** (Jan. 16) 47–9.

New Boiler Concepts Meet High Expectations. G. W. Bice, P. H. Koch and E. M. Griffin. *Elect. Wrld* 1961, **155** (Jan. 16) 50–3.

The design of the supercritical boiler for Breed station rated at 3250 klb/h at 3500 psi and 1050/1050/1050 F is described and the reasons for various modifications outlined. The boiler is fired by eight 10 ft dia. cyclone furnaces in the front and rear wall and recirculated gas is introduced at the top of the lower furnace. This is followed by the upper furnace, convection section with the secondary superheater, primary superheater, reheaters and economizer in vertical arrangement. Three regenerative air preheaters are installed on top of the convection section. The boiler is of the outdoor type and pressure-fired. Details are also given of furnace design, membrane furnace wall design, start-up by-pass system and steam temperature control.

Heat Cycle Refinements Yield 8376 Btu Heat Rate at 480 Mw. T. T. Frankenberg and J. A. Tillinghast. *Elect. Wrld* 1961, **155** (Jan. 16) 58–61.

The various factors which have contributed to the exceptionally low heat rate are detailed.

Station Controls are Closely Coordinated. A. S. Grimes and W. S. Morgan. *Elect. Wrld* 1961, **155** (Jan. 16) 62–4.

The control system for the boiler and turbogenerator is outlined. The central control room contains also the controls for a substation, switchyard and coal handling plant and an analogue computer for calculating and monitoring thermal performance.

Clean-Up System Prevents Feedwater Contamination. E. B. Morris and A. G. Lloyd. *Elect. Wrld* 1961, **155** (Jan. 16) 65–7.

The cleaning of the boiler prior to start-up was carried out by using 3 per cent citric acid for the reheaters, alkaline phosphate solution followed by 5 per cent hydrochloric acid for the condenser and feedwater cycle and 3 per cent citric acid for the steam generator. The feedwater make-up and condensate treatment plant is described and feedwater specifications tabulated.

Piping Design Integrates Factors of Size, Stress and Material. G. E. Lien and A. J. Breugelmans. *Elect. Wrld* 1961, **155** (Jan. 16) 68–70.

Details of piping layout planning, stress calculations and materials used for main and reheated steam lines, feedwater, by-pass system and condensate are presented.

Semi-Outdoor Structure Houses 500 Mw Compactly. H. A. Kammer and E. A. Kammer. *Elect. Wrld* 1961, **155** (Jan. 16) 75–8.

By placing the boiler and bunkers outdoors and a semi-outdoor type of superstructure for the other plant the enclosed part is only 13.3 ft³/kw. The chimney has a height of 597 ft from base to top. Also described are: 1. Coal supply and handling arrangements; 2. Coal sampling and storage; 3. Cooling water supply.

Utilization of Blast Furance Gas in the Boilers of the Farciennes Power Station. J. Godfroid. *Votre Electr.* 1961, **31** (Nov.) 13–30 (*In French*).

The boilers are rated at 72–90 t/h at 75 atü and 500 C and are fired by a mixture of coal and blast furance gas, the ratio depending on the availability of the gas. The gas burner used in this installation, the automatic controls and safety measures are described. The efficiency of the boiler is 88.7 per cent on coal and 85.1 per cent on a gas-coal mixture.

The Colliery Steam Power Station of Farciennes to the East of Charleroi. J. Godfroit. *Votre Electr.* 1960, **31** (Nov.) 31–8 (*In French*).

For the utilization of the low-grade coal produced in the coal treatment plant, such as dust of high ash content, middlings and slurries the Farcienne power station has been built by a group of collieries. It contains at present a boiler rated at 290/350 t/h, 150 atü and 540/540 C and a 100/110 Mw turbogenerator. The boiler is provided with burners for pulverized coal and blast furance gas.

The Paradise Steam Plant of the TVA. J. C. Voorhees. *Civ. Engng* 1961, **56** (Feb.) 192–3.

The construction has started of this power station which will contain the largest units ordered so far. It will consist of 2 units each.

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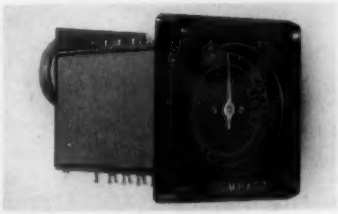

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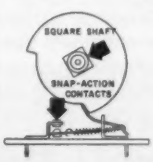

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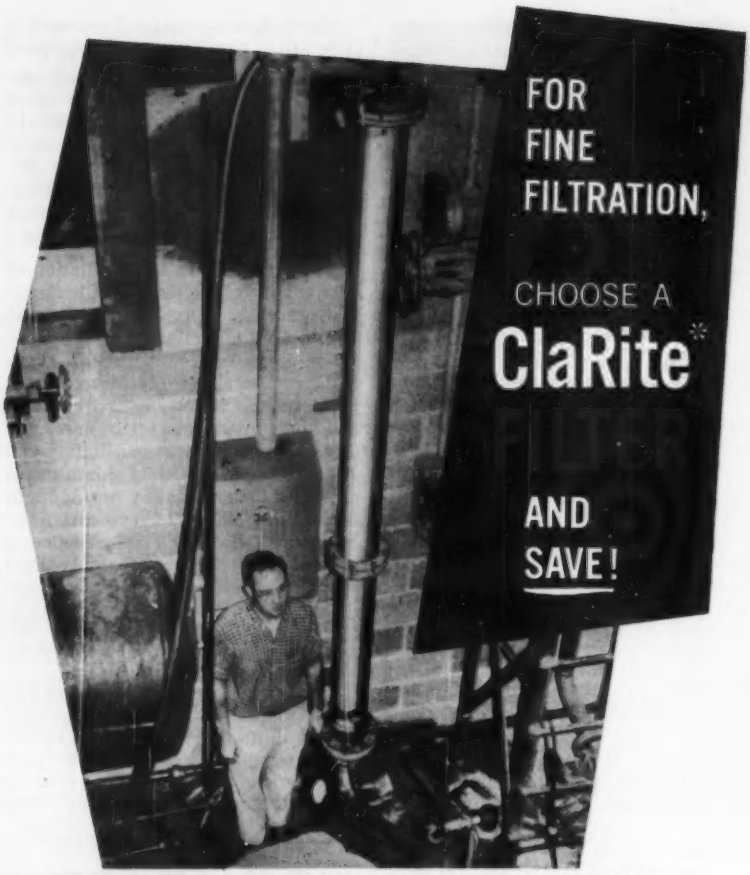

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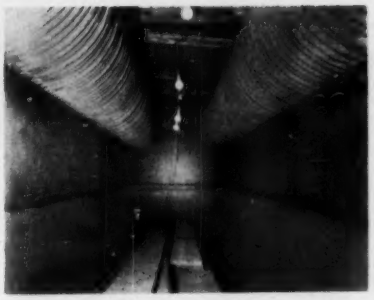

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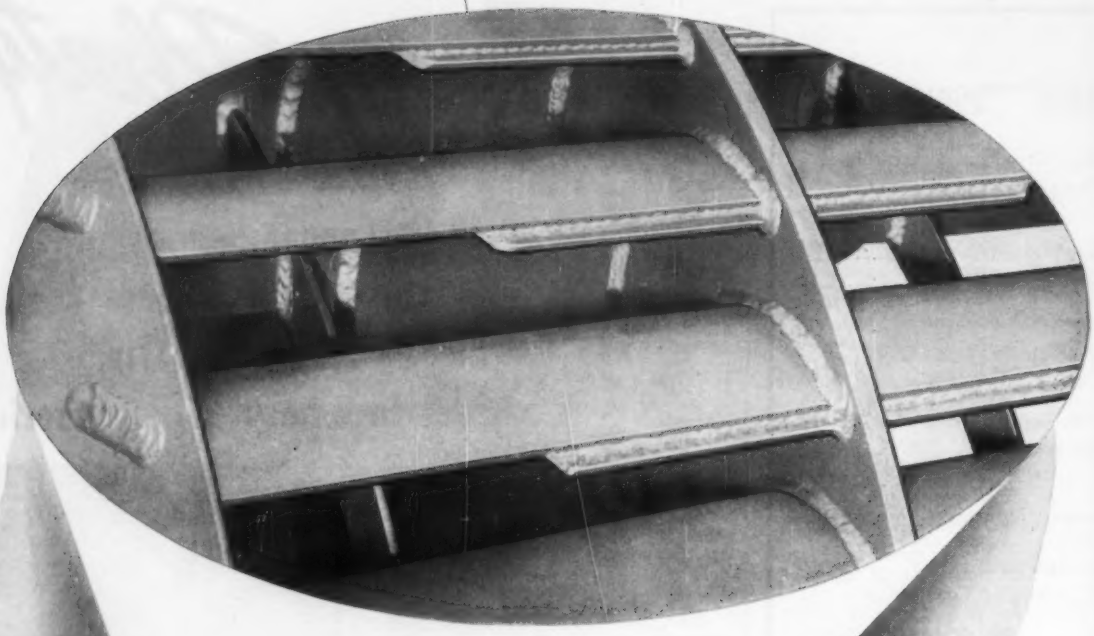

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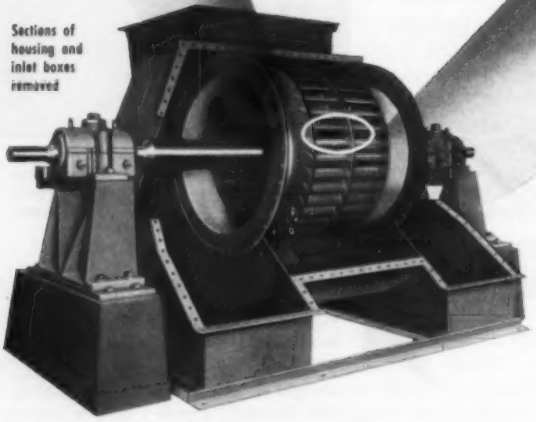

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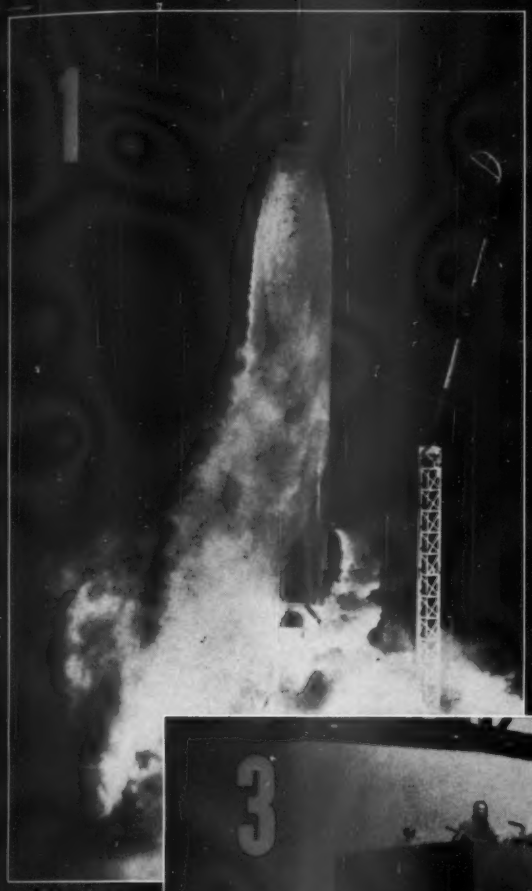

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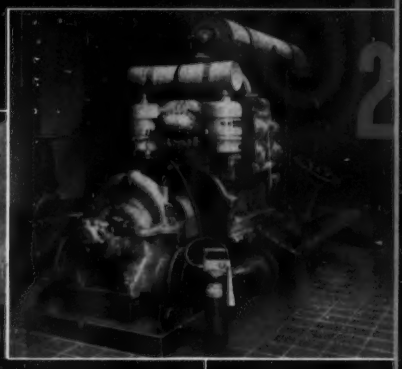

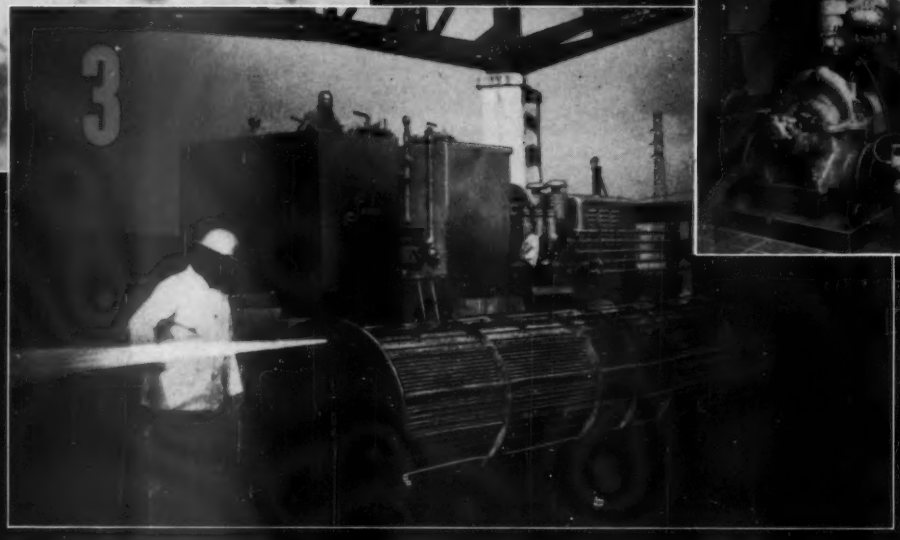

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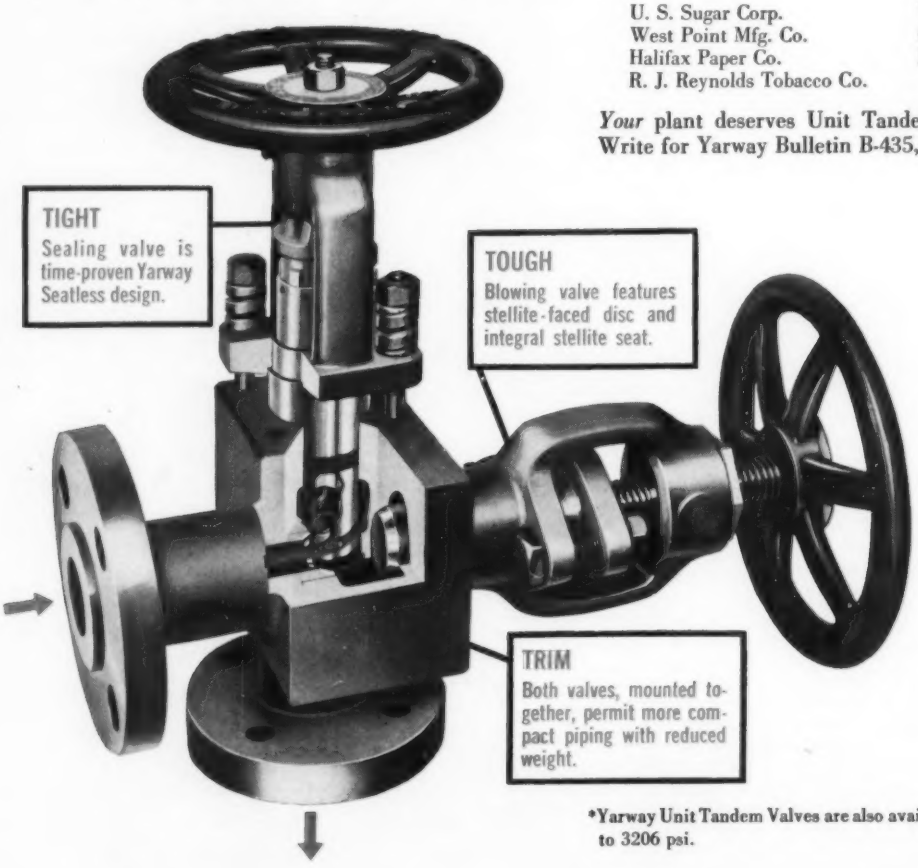
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